Volume 24 AUGUST, 1940 Number 8

BULLETIN
of the
American Association of Petroleum Geologists

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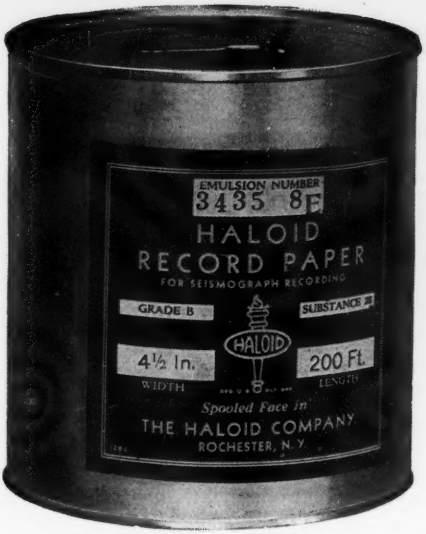

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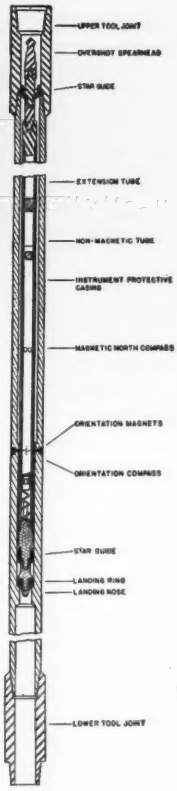

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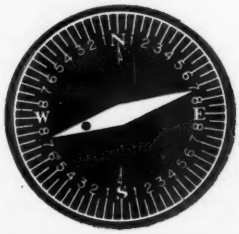

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By K. G. Bell, Clark Goodman, and W. L. Whitehead

Paleogene of Barbados and Its Bearing on History and Structure of Antillean-Caribbean Region

By Alfred Senn

Jurassic-Cretaceous (Girón) Beds in Colombia and Venezuela

By Victor Oppenheim

Paleozoic Limestone of Turner Valley, Alberta, Canada

By W. D. C. Mackenzie

Lower Ordovician Sand Zones (St. Peter) in Middle Tennessee

By Kendall E. Born

New Zone in Cook Mountain Formation, Crassatella texalta Harris—Turritella cortezi Bowles Zone

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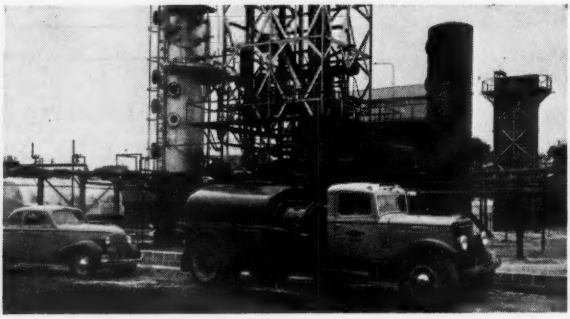

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Volume 24 Number 8

BULLETIN
of the
AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS

AUGUST, 1940

EXPLORATION METHODS

FOREWORD

Two symposia were sponsored by the research committee during the time of the annual meeting at Chicago, April 9 and 10, 1940.

One was on the subject of "New Ideas in Petroleum Exploration" and was held on the afternoon of April 10. The program consisted of the following.

Chairmen: A. I. Levorsen and M. G. Cheney

Speakers: A. I. Levorsen, "Introduction" and "Petroleum Geology"

P. E. Fitzgerald, "Chemical Engineering in Petroleum Exploration and production"

C. V. Millikan, "Petroleum Engineering as an Aid in Exploration Geology" (paper was read by A. R. Denison)

E. A. Eckhardt, "Geophysics"

E. E. Rosaire, "Geochemical Prospecting for Petroleum"

F. H. Lahee, "Where Will Young Graduates in Petroleum Geology Acquire Field Experience?"

E. DeGolyer, "Future Position of Petroleum Geology in the Oil Industry"

The other symposium was on "Geochemical Exploration (Soil Analysis)" and was the subject of the annual round-table discussion on the evening of April 9. The program consisted of formal papers by E. E. Rosaire and Eugene McDermott[1] and informal discussion by R. H. Fash, John W. Merritt, and Harold M. Smith. Written questions were answered from the platform and the unanswered questions were submitted to the speakers by mail.

[1] Eugene McDermott, "Geochemical Exploration (Soil Analysis)," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 24, No. 5 (May, 1940), pp. 859–81.

It is believed that the material presented at these symposia is of wide and timely interest to petroleum geologists and as a consequence it has been assembled into one issue of the *Bulletin*. A reporter was present at both meetings and all speakers have had an opportunity to edit their remarks. The style in several of the articles is rather informal as compared with the regular material published in the *Bulletin*, but this is thought to be desirable and effective.

A. I. LEVORSEN
Chairman, research committee

TULSA, OKLAHOMA
May 25, 1940

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
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SYMPOSIUM ON NEW IDEAS IN PETROLEUM EXPLORATION

PETROLEUM GEOLOGY[1]

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ABSTRACT

The continuing large numbers of students majoring in geology in our colleges and universities is a phase of our development which warrants the thoughtful attention of our membership. Since half or more of those who enter the field of geology enter petroleum geology in some form or other, an awareness of the problem is recommended to student, teacher, and employer.

We have witnessed, in the development of the methods of oil-field discovery, a progressive change from the relatively simple methods of surface geology of two and three decades ago to the complex approach of the present in which various techniques of geology and geophysics are employed. Each technique has risen to a peak of usefulness and then declined as the areas in which it would function were worked out. At present all of the methods of oil-field discovery previously used are past the crest of their usefulness and are in various stages of declining value. With the continuing demand for petroleum, what are the discovery and exploration methods of the future? This symposium is designed to bring out discussion of some of the elements which must be considered in attempting to formulate an answer to the problem.

In so far as petroleum geology is concerned, the dominant trend seems to be toward a more intensive and detailed study of stratigraphy, sedimentation, reservoir rocks, geologic history, and the varying environments of deposition. The materials used in this approach are the vast quantities of well cuttings, electric logs, and porosity and permeability data. Heretofore the study of this material has merely been an accessory to other methods of discovery. However, under the increasing influence and understanding of sedimentation—"the philosophy of the well cuttings"—this field of activity is changing from a passive to an active approach to discovery. As such, our horizons are pushed back enormously.

INTRODUCTION

As chairman of the research committee of the Association it is a pleasure to welcome each one of you here this afternoon. The research committee sincerely hopes that you will find something of interest and value in the program which is to follow. This program was designed to parade before you some of the new and current ideas and trends in petroleum exploration and the speakers have been asked to interpret these trends and ideas and point out their significance to petroleum geology. May I suggest that each of you sit back and put yourself in an objective and reflective frame of mind and we will attempt to give you something to take home and think over.

GEOLOGY STUDENTS

Table I shows the results of the research committee's surveys of college students in the United States, who are majoring in geology.

[1] Read before the Association at Chicago, April 10, 1940. Manuscript received, May 25, 1940.

[2] Chairman, American Association of Petroleum Geologists research committee.

Three points seem to be significant.

1. There is a slowing down of the increase in students from 1939 to 1940—the increase being approximately 3 per cent, whereas the increase from 1938 to 1939 was approximately 35 per cent.

2. There are more than 2,500 students majoring in geology in the United States at the present time. The last column probably reflects 90–95 per cent of the total enrollment down to junior grade in the colleges of the United States.

3. Approximately half of those leaving college who enter geology enter the field of petroleum geology.

TABLE I

STUDENT GEOLOGY MAJORS – U. S.

		1938	1939	1940	TOTAL 1940
UNDER-GRADUATE	JUNIORS	571	775	773	995
	SENIORS	418	575	628	765
GRADUATE	M. A.	229	360	336	402
	PH. D.	198	228	257	271
TOTALS		1416	1938	1994	2433
UPON LEAVING SCHOOL ENTERED	PETROLEUM	223	244		
	OTHER	216	265		

Results of surveys by research committee of number of college students in United States majoring in geology. First three columns show students in those schools which have reported for each of past 3 years and from which comparison may be made. These three columns probably reflect 75 per cent of total enrollment. Last column shows total from all schools reporting in 1940—some of which reported for first time. This column probably reflects 90 per cent or more of total enrollment in United States. Lower part of table shows relative number who, upon leaving school, entered petroleum geology and those entering other lines of geology—including graduate work in other colleges. These surveys are made as of January in each year.

There is no comment on these figures which the writer has to offer. Let each person interested fit them to his own circumstances and position. It does seem, however, that they should be of interest to the student or prospective student of geology, the teacher of geology, and to the employer of geologists.

PAST TRENDS IN PETROLEUM EXPLORATION

Figure 1 is a chart showing my conception of the gradual change in the dominant geological methods used in petroleum exploration. It is not to be considered as quantitative, but rather as qualitative—the sort of figure one makes on scratch paper, for example, in order to explain an idea.

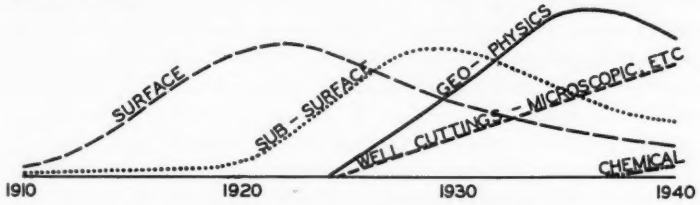

FIG. 1.—Chart showing changes in dominant geological methods employed in petroleum exploration.

The discovery methods are surface geology, subsurface geology, and geophysics. The search for favorable surface structure was the dominant method employed from 1910 to approximately 1925—reaching its peak development between 1920 and 1925—and since then declining to a relatively small proportion of the effort in 1940. Core drilling for structure would be included in this classification since it is mainly concerned with structure near the surface.

The philosophy was developed, as more and more wells were drilled, that the closer to the probable producing formation one could contour the structure, the more accurate the map, with a consequent better chance of success. This resulted in a large number of discovery prospects being drilled on subsurface structures that were thought to be favorable. The peak of this type of exploration was during the period of 1925 to 1930, and since then it has declined in its use as a discovery method. This is not to be confused with the routine subsurface mapping which goes on continually and which is largely a method of keeping records and furnishing clues as to favorable areas for applying other methods of attack.

It was and is extremely difficult to find the top of a subsurface structure by subsurface contouring alone—the high point has a habit of "sliding out" and commonly many test wells were necessary to locate the top. The theory of subsurface contouring was excellent, but the practice was poor. Geophysical methods, which came along in the middle 1920's, fast developed into accurate methods of determining structure just where it was most needed—down near the producing zone. As a result, the various geophysical methods, particularly the

seismic methods, have largely displaced strictly subsurface methods of determining discovery drilling locations.

However, the subsurface method, due to the necessity of drilling several wells in order to locate and test the top of the structure, frequently resulted in the discovery of oil in various sand lenses, porosity changes, and other stratigraphic type accumulations. On the other hand, the seismic method by its ability to locate accurately the top of the structure condemns all of the territory intervening between it and the next structure. In other words, the seismic method loses oil discovery by its accuracy which in many places the subsurface method gains by its inaccuracy.

All of these discovery methods are concerned solely with the finding and mapping of favorable structural traps capable of holding oil. Each has declined through no failure of the method—as a matter of fact each method can be practiced much more accurately now than in the past—but the decline is due chiefly to the fact that each method has been applied extensively and has more or less exhausted the territory in which it can work to advantage. Structures found 10 or 50 years hence by any of these methods should be just as good prospects as if they were found to-day, but the chances of finding new structures by these methods in the future becomes less and less each year as more areas are worked out.

Currently the only new approach to the problem of oil discovery is that of geochemical surveying (soil analysis) and it is yet in the experimental state. It is thought by its advocates that not only structural accumulations but stratigraphic accumulations as well can eventually be located.

The question then arises, what is to be the discovery method of the future, with all our present methods on the decline and the demand for petroleum on the increase? You will hear from experts in each of these fields this afternoon, as well as from the associated fields of petroleum engineering and chemical engineering—and it is to give you a better idea as to the possible solution of the problem and the trends in the thinking that this symposium was designed.

CURRENT AND FUTURE TRENDS IN PETROLEUM GEOLOGY

May I say just a word as to what I believe to be the trend in the field of pure geology to the problem of oil-field discovery? You will hear from speakers representing each of the other methods in vogue as well as from the petroleum and chemical engineering field, but no one is scheduled to speak for geology as such—and you might conclude that we who are geologists have no answer. However, I believe we do have

an answer and that it largely lies along the line on Figure 1 labelled "Well Cuttings, Microscopic, etc."—which includes all the various techniques of detailed stratigraphic analysis, and particularly includes the various forms of electric well logging. It is the fastest growing group in our profession. Heretofore the justification for the expense of gathering, filing, and analyzing these tons upon tons of well cuttings has been their use as an accessory to the production department or to the discovery methods of geophysics and subsurface geology. The operator wants to know, first, is the well running high, low, or indifferent? and second, is he drilling above, in, or below the potential producing formation? Beyond that he is generally not interested in samples or what they can do for him. This line of "Well Cuttings, etc." therefore has merely been a passive approach, or no approach, to discovery—in other words, except in a few areas, it is not being used as a method of locating wildcat wells.

There is, however, a rather interesting and significant change developing in our attitude. We have lately been adding large doses of of what we call "sedimentation" to our thinking. I do not know what the orthodox definition of this word is, but to me as a petroleum geologist, "sedimentation" means the philosophy of well cuttings—the underlying meaning of these well samples. We have seen a tremendous movement into this sort of thinking during the last year or two. For example, last year the research committee conducted a survey of the members of the Association, asking them for their opinion as to the most fruitful lines of research in the field of petroleum geology. The majority were in favor of the related fields of sedimentation, stratigraphy, and reservoir-rock studies of porosity and permeability. Furthermore, in the last year or so there have been three notable books published on the subject. One, *Principles of Sedimentation*, by Twenhofel,[3] approaches the subject from the ecological and environmental point of view; another, *Manual of Sedimentary Petrography*, by Krumbein and Pettijohn,[4] deals with the laboratory and mechanical elements of the subject; while another, *Recent Marine Sediments*,[5] published by the Association and consisting of 34 articles by 31 authors under the editorship of Parker D. Trask, describes modern sediments the world over. One other indication of the increased interest in the subject is the widespread attendance in the sedimentation study

[3] W. H. Twenhofel, *Principles of Sedimentation*. McGraw-Hill Book Company, Inc., New York (1939).

[4] W. C. Krumbein and F. J. Pettijohn, *Manual of Sedimentary Petrography*. D. Appleton-Century Company, New York-London (1938).

[5] *Recent Marine Sediments*, a symposium edited by Parker D. Trask. American Association of Petroleum Geologists, Tulsa, Oklahoma (1939).

groups being organized in many of the geological centers. These are mentioned to show the current trend in our thinking—we are attempting to make better use of the materials which have been accumulating over these many years—we are attempting to understand them and their meaning in terms of oil-field environments.

As we add sedimentation to "Well Cuttings, etc." we are gradually changing this line from purely a passive accessory to other discovery methods into an active and aggressive oil-finding method in itself.

As such it is not as simple in its approach as our old methods of finding closed structures—the contour pictures of which are understandable to the average layman with only slight experience. As a matter of fact, our progress has always been limited by the ability of the land man, oil-company executive, or operator to understand what we were driving at. They learned to understand contours and it is therefore relatively easy to get them enthused about exploring almost anything with a good-looking contour map. Unless, then, they learn to understand the application of sedimentation and the uses to which well cuttings may be put, there will be little active support for this type of exploration—because, after all, these are the men who hold the purse strings. In other words, those companies and operators who are most geologically minded will have the better chance of reaping the benefits of sedimentation studies as applied to oil-field discovery.

The great volume of well cuttings which have accumulated in the development of this upward-trending line of "Well Cuttings, etc." (Fig. 1) seems to me to represent one of the great assets of the petroleum geologist. These well samples were collected by and for him and there is no one else who can do anything with them. The geophysicists can do nothing with them, the engineer can do nothing with them, and the geochemist can do nothing with them—they are reserved for the exclusive use of the petroleum geologist. They represent material upon which we, more than anyone else, can apply our imagination, our philosophy, our logic, and our reason for years and years to come.

In conclusion, it seems to me that the golden age of petroleum geology may still be ahead of us. We have been wandering around on the plains where the paths are straight and easy to follow. We are now coming into the foothills—and with but even a slight increase in elevation, our horizons are pushed back enormously. We still have the plateaus and the mountains ahead!

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CHEMICAL ENGINEERING IN PETROLEUM EXPLORATION AND PRODUCTION[1]

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ABSTRACT

The use of chemicals in wells was begun about 45 years ago in Ohio, but it was not until early in 1932, when inhibitors to prevent acid corrosion were developed, that the acidizing process became commercial. Various developments which followed the successful application of inhibited acid to wells led to the development of other materials and technique. Some of the more important chemical addition agents which have become important in this field are surface-tension reducing compounds, stabilizers to prevent secondary precipitation, emulsion preventers, and chemicals to regulate the reaction rates of acid on various types of reservoir rocks.

Research of this type naturally led to other drilling and production problems which have resulted in the commercial application of chemicals for the control of undesirable fluids in wells. The use of plastics in the laboratory analyses of cores is also mentioned.

Chemicals and equipment for drilling lateral holes into oil-producing formations are discussed, and it is pointed out that if the process becomes efficient and economical, decided advantages will be obtained. One of these will be greater oil recovery. Also briefly discussed is a new method of perforating pipe with abrasive fluids.

This paper briefly mentions the research on the nature of drilling clays and fluids and the effect of chemicals on the properties of these fluids. The use of certain chemicals to overcome heaving shale on the Gulf Coast is also mentioned.

Although consideration was given to the employment of chemicals for increasing oil and gas production more than 45 years ago, it has been only during the last decade that chemistry has become an important factor in petroleum exploration and production. It was probably Frasch[3] and Van Dyke[4] who made the first studies of the application of chemical engineering knowledge to the production phase of the petroleum industry. In any event two patents were issued to them involving the use of hydrochloric and sulphuric acids to increase oil production from limestones.

It was not until 1932, however, that Grebe and Sanford[5] developed their acidizing method in which the action of the acid against metals was inhibited to minimize acid corrosion and thus make the commercial application of acidizing wells possible. Later in 1932 Carr[6] introduced his method of confining the acid solution to a certain specific horizon, and the acidizing process became increasingly widespread. Acidizing has since become a part of nearly every well completion in

[1] Read before the Association, April 10, 1940. Manuscript received, May 25, 1940.

[2] Research geologist, Dowell Incorporated.

[3] Herman Frasch, U. S. Patent 556,669. 1896.

[4] John W. Van Dyke, U. S. Patent 556,651. 1896.

[5] J. J. Grebe and Ross T. Sanford, U. S. Patent 1,877,504. 1932.

[6] R. H. Carr, U. S. Patent 1,891,667. 1932.

areas where oil and gas are obtained from predominantly limestone rocks.

Perhaps the greatest effect of chemical engineering in the producing branch of the petroleum industry has been a complete change in the attitude toward oil reservoirs composed of limestones. This has been proved by the widespread development in western Kansas, Michigan, Illinois, and the Permian basin. The knowledge that petroleum might be found in limestones in certain areas has intensified, rather than delayed, the search for oil and gas in these areas. This has all happened during a depression period when there has been no apparent shortage of oil, nor has there been a universal let-down of the restrictions curtailing production.

During this period much research has been carried on by the chemist and engineer to develop and improve the chemicals and techniques used in well treating. One of the principal goals of research in this field has been to develop a group of chemicals that will produce optimum results and no harm to the well.

Some of the more important developments in acidizing of wells have been (1) improvements in inhibitors to minimize corrosion, (2) discovery of stabilizers to reduce secondary precipitation of metals which might cause reduction of the permeability of the producing formation, (3) application of surface-tension agents to overcome difficulties of injection into the formation and incomplete removal of the spent acid products from the producing zone, (4) use of wetting agents to aid in speeding up the chemical reaction by dispersing the oil coating of the rock, (5) employment of agents to minimize emulsion formation when oil, gas, spent acid, and other materials come in contact with each other in the reservoir, (6) discovery of addition agents capable of increasing the rate of reaction of the acid on dolomitic or siliceous limestones and of agents to retard the reaction rate in pure, fast reacting limestones such as the Ste. Genevieve (McClosky) of Illinois, Kansas City of Kansas, and Hunton of Oklahoma.

It is difficult to evaluate the net result of chemical treatment of wells because of the many variables that must be considered. However, in the formations which respond favorably to chemical treating, such as those in western Kansas, data[7] are available which show that the ultimate recovery has been increased. Competent engineers estimate also that at least 50 per cent of the wells completed in the Arbuckle limestone would have been abandoned as dry holes except for

[7] R. E. Heithecker, "Effect of Acid Treatment upon the Ultimate Recovery of Oil from Some Limestone Fields of Kansas," *U. S. Bur. Mines R. I. 3445* (April, 1939), p. 41.

the acidizing process. It is the opinion of the writer that the trend in chemical treating of oil wells has been and will continue to be a steady progress from the early haphazard dumping of chemicals into a well to the present highly scientific approach, in which all controlling factors are analyzed and evaluated prior to the actual treatment of the well.

It was only natural that the chemical engineer doing research in the field of petroleum production would be attracted to the other problems confronting the operator. One of these was the shutting-off of water sands in wells drilled by cable tools to eliminate the use of expensive casing. As early as 1920 some visionary engineers were devoting their attention to the use of chemicals to control water in wells. Patents were granted to Mills[8] and Swan[9] involving the use of such materials as sodium silicate, sodium carbonate and solidified naphthalene which could be used for such purposes.

More recently Kennedy[10] published a paper discussing the use of silicon tetrachloride as a means of water control in producing wells. In 1936 Heald[11] called attention to the work already done and pointed out the future possibilities of chemical water control.

During the last two years much work has been conducted both in the laboratory and the field, which has resulted in the commercial control of undesirable fluids from certain types of wells. The laboratory experiments and field results of this work have been described by Fitzgerald,[12] and Lehnhard and Reimers.[13] These papers discuss non-selective, delayed-setting gels whose time of setting can be controlled. These chemicals do not contain any suspended material to filter out on the face of the formation as in the case of cement. On the other hand, it is not intended that they shall replace cement because they do not set to the rigid mass characteristic of cement. However, laboratory tests on 1-inch cores taken from oil-producing formations show that when they are plugged with these materials under atmospheric pressures they will withstand pressure differentials as great as 1,000 pounds per square inch.

[8] R. van A. Mills, U. S. Patent 1,421,706. 1922.

[9] Swan, U. S. Patent 1,379,657. 1921.

[10] H. T. Kennedy, "Chemical Methods for Shutting Off Water in Oil and Gas Wells," *Trans. A.I.M.E.*, Vol. 118 (1936), pp. 1–8.

[11] K. C. Heald, "Deep Well Drilling Problems and Their Solution," *A. P. I. Drilling and Production Practice* (1936), p. 46.

[12] P. E. Fitzgerald, "Improvements to Chemical Treatments of Oil and Gas Wells," *A.P.I. Paper 826–10F* (April 4, 1939), pp. 1–3.

[13] P. J. Lehnhard and Hans Reimers, "Chemical Formation Plugging," *Oil Weekly* (July 10, 1939), p. 15.

Generally speaking, the delayed-setting gels are non-selective and will set up in the usual media encountered, whether it be oil, gas, water, or brine. They have been used successfully in combination wells, but with the aid of mechanical devices such as packers and bridging plugs. Figure 1 shows data compiled from field applications of this type of chemical plug. Of particular present interest is the discovery of their use as a successful and economical means of controlling gas-oil ratios.

CHEMICAL WATER CONTROL

STATE	FORMATION	GALS USED	PRODUCTION		REMARKS
			BEFORE	AFTER	
TEXAS	PERMIAN	600	6 BBLS. WATER/HR.	65 IN 12 HRS.	DRILLING WELL
TEXAS	PERMIAN	1500	7 BBLS WATER/HR	0	DRILLING WELL
TEXAS	PERMIAN	1500	222 BBLS W 2 BBLS OIL	1/2 BBL/HR 0 OIL	OLD WELL DRILLED DEEPER
TEXAS	PERMIAN	1500	12 BBLS WATER/HR	0	DRILLING WELL
TEXAS	PERMIAN	500	GOR 13,671	NOW GAS LIFTED	GOR REDUCTION
TEXAS	PERMIAN	750	GOR 15,720	NOW GAS LIFTED	GOR REDUCTION
TEXAS	PERMIAN	1500	13 M GAS 0 OIL	430 M GAS 15 OIL	AFTER ACID 430 M AND 44 OIL
N. MEX.	YATES	2800	25 M/DAY	1 M/DAY	DRILLING WELL
OKLA.	SIMPSON	2000	535 WATER 1 OIL	360 WATER 18 OIL	1700% OIL INCREASE
OKLA.	VIOLA - SIMPSON	4000	1360 WATER 48 OIL	148 WATER 48 OIL	89% WATER SHUT-OFF NO OIL SHUT-OFF
OKLA.	WILCOX	2000	350 WATER 11 OIL	0 WATER 0 OIL	ALL FLUIDS SHUT OFF
MICH.	TRAVERSE	1000	96	0	DRILLING WELL
ILLINOIS	PENN	1000	312	0	DRILLING WELL
KANSAS	ARBUCKLE	800	636 WATER 14 OIL	290 WATER 33 OIL	MECHANICAL SELECTIVITY

FIG. 1

Another method[14] for the chemical control of water-oil ratios is being studied experimentally at the University of Texas. This method involves the use of chemicals which, when introduced into the pay zones, tend to make the formation preferentially wet to oil so that the well may be produced with a lower water-oil ratio.

Another application of these chemical plugs has been their use in laboratory analysis of cores. This technique involves the impregnation of the core sample with chemicals which change to insoluble solids with varying time, pressure, or temperature. The matrix can be dissolved away leaving a spongy mass which is a model of the porosity. Laboratory methods such as this will undoubtedly have an important bearing on sedimentation, porosity, and permeability problems.

[14] F. B. Plummer and H. K. Livingston, "Reduction of Water in Experimental Oil Wells," A.I.M.E. annual meeting, New York, February, 1940.

Almost since the beginning of the petroleum industry, forward-thinking men have been attempting to devise tools with which to drill lateral holes into an oil-producing formation. All of these have been mechanical devices involving rotary or percussion processes. The most successful recent lateral drilling has been done in eastern Ohio along an outcrop and is described in a paper by Ranney.[15] This method can also be used in buried formations provided a shaft large enough to accommodate drilling operations is sunk to the pay zone.

Chemicals have been utilized in conventional drilling operations for more than 50 years as witnessed by a patent[16] issued to Albert Krause in 1887, which included the use of various acids as an aid to cable-tool drilling operations.

It has only been during the last few years, however, that attention has been called to the possibilities of chemicals as a means of drilling horizontal holes in deeply buried oil-producing formations. Research carried on in the laboratory and field has resulted in the development of a horizontal drilling device which utilizes a flexible, armored hose, hose guide, and suitable jets. The hose with a jet on the bottom end is lowered into the well on a string of small tubing. The small tubing assembly is introduced into the well through the conventional tubing string which has the hose guide at its lower end. The small pipe is attached to a weight indicator which provides a means of controlling the contact pressure of the jet against the formation. The hose guide directs the armored hose and the jet against the formation. Chemicals capable of solvent action are pumped into the small tubing and thence through the jet against the formation. The combination solvent and jetting action drills a hole into the formation.

This tool has been used experimentally in several areas, and in Kansas a hole was drilled laterally a distance of 40 feet into the Kansas City formation. Figure 2 illustrates some of the salient points of this chemical drill.

Some of the factors to be considered if this type of drilling becomes practical are its effect upon well spacing, ultimate recovery, and possibly proration. There is no doubt that such a well-completion method would permit a more efficient use of available reservoir energy by reducing the pressure differential necessary to cause flow of oil into the well. By drilling several holes laterally a distance of about 10 feet the oil can be produced with probably one half the pressure dif-

[15] Leo T. Ranney, "Horizontal Drilling through Outcrop Brings Results," *Oil and Gas. Jour.* (April 20, 1939), pp. 68–69.

[16] Albert Krause, U. S. Patent 372,154. 1887.

ferential drop since it has been proved experimentally by Uren[17] and theoretically by Muskat[18] that about 50 per cent or more of the available energy is dissipated within 10 feet of the well.

If these horizontal holes are drilled in formations that lend themselves to chemical treatments, the pressure differential will be reduced still more, allowing for a more efficient use of the available reservoir energy.

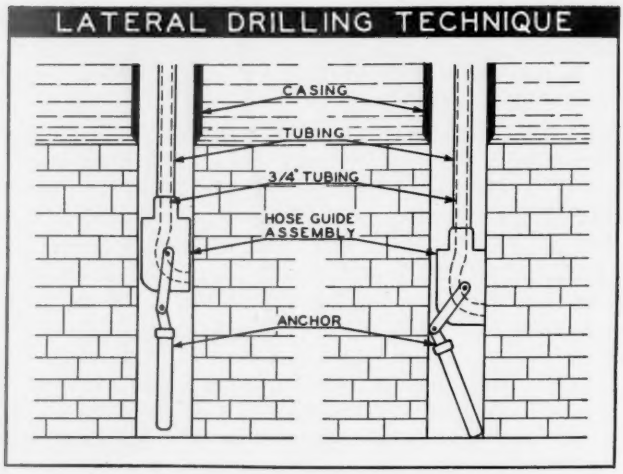

FIG. 2

The tendency of water coning through vertical permeability would be minimized also and in a gas-drive field it is probable that the economic life of the well would be longer.

Present well-completion practices frequently include electrical logging, running pipe to total depth, cementing and perforating the casing opposite its pay zones. The most common method of perforating the casing is by means of a gun which fires a 0.45-inch bullet through the casing and the cement behind it. Usually this method of perforating is quite successful but there have been reported cases

[17] L. C. Uren, J. Domercq, and J. Mejia, "Influence of Well Diameter upon Pressure Gradient and Rate of Flow of Oil through the Reservoir Rock in the Vicinity of a High Pressure Well," *Trans. A.I.M.E.*, Vol. 114 (1935), pp. 25–37.

[18] M. Muskat, *Flow of Homogenous Fluids through Porous Media.* McGraw-Hill Company, Inc., New York (1937), pp. 155–56.

where the bullets did not fully penetrate the cement. That they did penetrate the pipe is evidenced by subsequent use of chemicals which were forced through the bullet holes to disintegrate the cement and mud sheath behind the pipe.

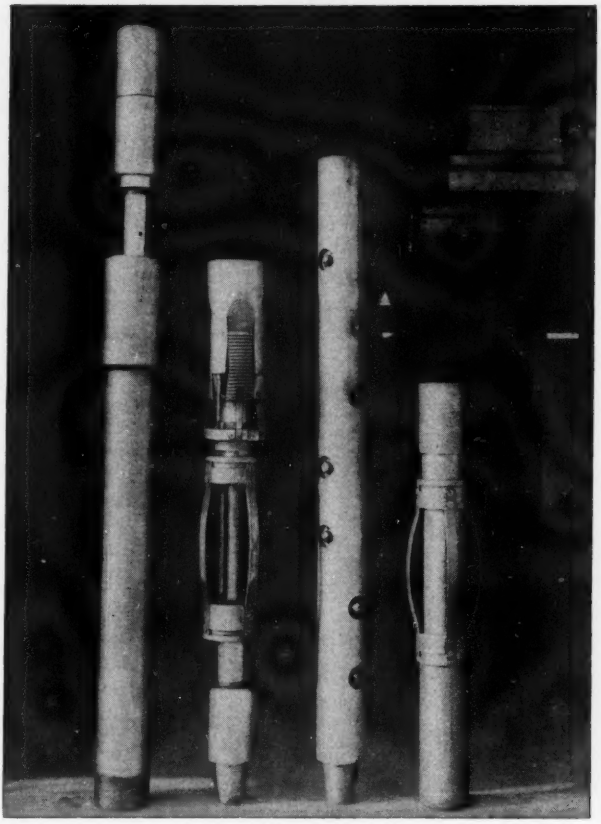

FIG. 3

Large-scale laboratory and field work already completed indicates that abrasives can be used effectively to perforate the casing and the materials behind the pipe. This method of perforating employs a high-velocity stream of abrasive fluid capable of eroding a window in the pipe and in the material behind the pipe. The well equipment which is run into the well on the bottom of tubing or drill pipe is shown in

Figure 3. In addition suitable high pressure, high-volume pumps and prime movers are needed to carry out this type of work. In California recently 184 holes were made in 36-pound $6\frac{5}{8}$-inch pipe in 8 hours and 40 minutes.

A similar gun has been used effectively to direct jets of acid against the walls of the well bore to increase the drainage area of the well.

Of much interest to geologists have been the efforts of chemical engineers to improve drilling fluids. Growth of knowledge resulting from research in this field has been phenomenal during the last few years. Much valuable insight into the nature of drilling fluids has been obtained and more is known about the composition of clays and shales and the surface chemistry of clay minerals. As the knowledge in this field increases more and more, attention will be given to the effects of chemicals on the properties of drilling muds. Already there is in common usage a group of agents that overcome or control viscosity increases of the rotary fluids. These viscosity increases make the mud difficult to handle, increase the thickness of the filter cake, water loss into the formation, and increase the dangers due to gas cutting. According to Robinson[19] some of the factors that contribute to viscosity increases are: (1) accumulation of solids, (2) base exchange, (3) loss of deflocculating agents, (4) presence of flocculating agents in connate water of the formations penetrated, (5) temperature, and (6) increased colloidal dispersion and hydration of natural clays and shales.

The special Gulf Coast problem of drilling through heaving shales[20] has been of the utmost importance to the geologists since these exceptional formations have made the exploration of deeper formations almost impossible. The chemist has given much of his attention to the solution of this problem, the chemical control[21] of which is based on the fact that certain types of these shales are altered by the water in the rotary fluid as they are drilled.

One of the most interesting methods suggested for chemical control of heaving shale is the use of a drilling fluid containing a substantial amount of sodium silicate. The advantage of silicate mud is ex-

[19] W. W. Robinson, Jr., "The Application of Chemicals for Drilling and Producing Operations," *A.P.I. Paper 801-160* (March, 1940), pp. 9–14.

[20] J. M. Frost, III, "Geologic Aspects of Heaving Shale in Texas Coastal Plain," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 23, No. 2 (February, 1939), p. 212.

[21] C. L. Baker and A. D. Garrison, "Chemical Control of Heaving Shale," *Oil Weekly* (February 6, 1939), p. 21.

plained[22] by the tendency of the heaving shale to keep the water from the drilling fluid at a pH of 7 to 9. The pH of silicate mud is about 11. The buffeting effect of the shale tends to reduce the pH of the mud, causing the precipitation of a film of silica gel over the face of the shale, thereby reducing its tendency to heave.

Chemical engineering as applied to the exploration for and production of petroleum is firmly established and there can be no doubt of its present economic importance. Furthermore, progress is continually being made on many fronts which have a direct relation to petroleum geology. There is no limit to the progress which can be made if the geologist and the chemist approach the problems in a coöperative manner. In this field the chemist needs more geology and the geologist more chemistry.

[22] W. V. Vietti and A. D. Garrison, U. S. Patents 2,165,823 and 2,165,824. July 11, 1934.

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PETROLEUM ENGINEERING AS AN AID IN EXPLORATION GEOLOGY[1]

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ABSTRACT

Petroleum engineering contributes to geological knowledge by making and interpreting tests in drilling and producing wells. Core analysis, mud analysis, and electric logs indicate the presence of oil and gas, and a preliminary test may be made through the drill stem. Production and bottom-hole pressure tests prove the stability of the reservoir, indicate its extent and, in some cases, correlation between wells. Improved methods of completing and repairing wells have permitted exploitation of smaller and thinner reservoirs. Better testing methods and more economical drilling have extended the range of exploration both in area and in depth. Many of these advancements of petroleum engineering have been made in the past 3 years or less and promise to continue at an accelerated rate. There will be a parallel increase in their importance to the geologist in his solution of subsurface problems.

Geology, petroleum engineering, and development and production practice are distinct in their functions of oil-field exploration and development. Even though they are essentially distinct they so overlap that no demarcation can be made. Geology provides the information for locating the first well in an area. Thereafter all three must combine to secure a thorough test of all formations penetrated and, when a discovery is made, the subsequent development and operation of the producing field.

Drilling the first well in an area provides information about the subsurface geology and other information for interpretations that will add to geological knowledge. A well drilled by cable tools amply tests each formation as it is penetrated. Oil or gas reservoirs must be determined by interpretation and testing in rotary-drilled holes. Interpretation is made from examination of drill cuttings, showings of oil or gas in the rotary mud, electric logs, and cores. Tests are made by analyzing the rotary mud and more definitely by analyzing the cores or making drill-stem tests. After the first well is completed as a producer, production tests and bottom-hole pressure tests, both static and flowing, are made. These data, combined with core analyses and with the geology, form the basis of a preliminary estimate of probable value of the prospect which is used as a guide for further development. Additional development adds data on reservoir conditions and provides a history to confirm or change earlier interpretations and calculations.

Drilling mud has always been watched for showings of oil and gas

[1] Read before the Association at Chicago, April 10, 1940. Manuscript received, May 27, 1940.

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and recently methods have been used to examine the mud for showings that might escape observation.[3] Most crude petroleums are fluorescent[4] under ultra-violet light, but so also are many of the lubricating oils used on the equipment. Experience thus far is not sufficient to place unqualified reliance on examinations. Gas determinations are made by trapping any gas that may be entrained in the mud and analyzing for hydrocarbon content. Neither ultra-violet light nor gas analysis has been used long enough to prove the limits of its application but the work is encouraging for more general adoption, particularly on wildcats.

Tests are made on mud in order to determine if a reservoir which has been penetrated contains salt water. Analysis can be made for chloride content of the filtrate, but measuring the electric conductivity or resistance of the mud is equally sensitive and more easily determined. Results are not too encouraging thus far but are sufficient to justify determining in conjunction with other testing. Experience will make interpretations more reliable. One of the difficulties is that water filters out of the drilling mud into the formation ahead of the bit, replacing a large part of the salt water in the formation before it is cut with the bit.

Ordinarily the amount of oil and gas that enters the mud stream during drilling of a reservoir formation is small. Some reservoirs may have a higher reservoir pressure than the hydrostatic head of the drilling mud.[5] This causes an abnormal showing of oil or gas in the mud and may be given a too optimistic interpretation. As a general rule a reservoir in which the pressure is considerably in excess of the hydrostatic head for the depth is in most cases not an important producer of gas, and even less probably of oil. There are exceptions to this general observation, but when such showings are obtained they should not cause undue encouragement.

Core-analysis methods have become almost a standard procedure. Accuracy of interpretation has improved greatly, especially during the past few years.[6,7] Proving the presence of appreciable quantities

[3] "Continuous Determination of Oil and Gas Content of Drilling Mud Helpful," *Oil Weekly* (August 1, 1938), p. 18.
"Automatic Sampling of Drilling Mud Achieved by New Device," *Oil and Gas Jour.* (February 17, 1938).

[4] A. L. Smith, "Ultraviolet Ray Examination of Drilling Mud," *Amer. Inst. Min. Met. Eng.*, fall meeting, November, 1939.

[5] C. V. Millikan, "Geological Application of Bottom-Hole Pressures," *Bull. Amer. Assoc. Petrol. Geol.* Vol. 16, No. 9 (September, 1932), p. 891.

[6] John H. Campbell and James A. Lewis, "Core Analysis Application to Well Completion," *Oil Weekly* (July 25, 1938).

[7] Howard C. Pyle and John E. Sherborne, "Core Analysis," *Trans. Amer. Inst. Min. Met. Eng.*, Vol. 132, "Petroleum Development and Technology, 1939," pp. 33–61.

of connate water in oil sands by analyzing cores taken under special conditions[8] to eliminate possibility of water contamination from drilling fluid has materially changed conceptions of the efficiency of recovery methods. Experience is making determination of connate-water content of cores taken under normal conditions more reliable. Analysis of cores of unconsolidated sand has room for improvement but has much value now whereas a few years ago it was considered that enough additional information could not be obtained to justify analyzing. Little progress has been made in obtaining satisfactory core analysis of limestone formations. This is partly due to inability to obtain satisfactory cores and, even though a complete core is obtained, too commonly it is not representative of the reservoir within the drainage area of the well. With all the precision available on core analyses and their interpretation, there is still opportunity for much advancement in correlation with producing-well performance.

Core orientation has much value when it can be obtained. Several methods, including an oriented core barrel and magnetic orientation of the core taken with a regular core barrel, are used. Orienting cores has a number of difficult problems, but probably most discouraging is the uncertainty of obtaining a core with reliable bedding planes to determine the dip.

Taking side-wall cores after drilling is completed is rapidly increasing in use. While the cores are not as suitable for precise analysis as regular cores, after some experience in analysis and interpretation it may be anticipated that results comparable with unconsolidated cores may be obtained.

Electric logging has become standard practice in most areas. While originally designed for interpreting presence or absence of oil and gas reservoirs, the use of the logs has been extended to stratigraphic studies and correlation, and their importance has increased for interpreting reservoirs and reservoir content. Considerable work has been done in correlating electric logs quantitatively with reservoir conditions. In one field a company has sufficient data on correlation of electric logs and core analyses that it is now evaluating the producing sand entirely with the electric log. It will probably require considerable experience in any field before the electric log can be used to determine sand conditions quantitatively but it now appears certain that it can be done in many areas. Electric logging concurrent with drilling, by using the bit as an electrode, has been successfully tested in several

[8] Ralph J. Schilthuis, "Connate Water in Oil and Gas Sands," *ibid.*, Vol. 127 (1938), pp. 192–214.

wells to about 5,000 feet, and has considerable promise of being a valuable contribution to exploratory drilling.[9]

Bottom-hole or depth pressures are used primarily to determine reservoir conditions in a developed field. The application of bottom-hole pressures to exploration has been limited primarily to drill-stem tests.[10] A bottom-hole pressure record during a drill-stem test will provide reasonably reliable information on the productivity of the well. After a well has been completed a flowing test gives more complete information on reservoir conditions.[11] The productivity can be determined with precision and the rate of pressure decline during the flow test will provide information about the stability of the reservoir. The rate of build-up of pressure at the bottom of the hole when the well is shut in following a production test will confirm interpretations of the flowing pressures and in some cases may give better data on the stability of the reservoir than the flow test itself. Production and pressure tests on salt-water sands are of value. A sand which contains salt water may contain oil or gas in another area of the same reservoir and its productivity would probably be comparable with its ability to produce salt water. Correlation of reservoirs may be made on the pressures within the reservoirs.[12] If the initial pressures are substantially the same there may be some question as to whether the reservoirs are or are not the same, but if the pressures are substantially different it is certain that the reservoirs are not the same even though they may be in the same stratigraphic position or even definitely correlated as the same stratum. Such determinations become of particular value in areas in which it is difficult to make correlations because of faulting or rapid changes in stratigraphy.

Water analyses have been used in oil-field operation for many years and some companies have sufficient data to make, in some cases, reasonably reliable correlations of source of water over a considerable area.[13] Confusion frequently results from an assumption that a particular reservoir stratum which can be definitely correlated in a considerable area is one continuous reservoir. Water analysis may or

[9] D. G. Hawthorn and John E. Owen, "Mechanical Practicability of Electric Logging while Drilling," *Petroleum Engineer* (January, 1940), p. 71.

[10] R. S. Christie, "Use of Recording Pressure Gauges in Drill-Stem Tests," *Amer. Petrol. Inst. Drilling and Production Practice* (1936), p. 8.

[11] T. V. Moore, R. J. Schilthuis, and Wm. Hurst, "Determination of Permeability from Field Data," *Amer. Petrol. Inst. Prod. Bull. 211* (1933), p. 4.

[12] C. V. Millikan, "Geological Application of Bottom-Hole Pressures," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 16, No. 9 (September, 1932), p. 891.

[13] "Oil-Field Waters," *Problems of Petroleum Geology* (Amer. Assoc. Petrol. Geol., 1934), pp. 833–985.

may not be correlated. Under such conditions reservoir-pressure determination may be helpful. Certain water analyses have been used to indicate the possible presence or absence of oil in a reservoir. An example of this is that in some areas the presence of sulphur water or fresh water is interpreted as a discouraging prospect for oil and gas while salt water may be encouraging or indifferent.

A drill-stem test involves risk of sticking the drill pipe which risk increases rapidly with depth. Chances of a successful test are also reduced with depth because of the high hydrostatic pressure that must be held by the packer while the testing tool is open. In general, the practical limits of depths for drill-stem tests are between 7,000 and 9,000 feet, depending on condition of the hole, the mud, and competency of the formation in which the packer must be set. Improved drilling mud has reduced the risk of deeper tests. Completion of wells by gun perforations which can be cemented off if the productivity of the formation is not satisfactory has reduced the importance of determining the productivity of a formation with a drill-stem test. Better interpretation of drill cuttings, cores, and mud analysis has also reduced the need for drill-stem tests.

Completion of wells through gun perforations of casing has been an important development for exploratory wells as well as a development practice. It has obviated the necessity of setting extra strings of casing to test each prospective producing formation. It permits testing the entire section of producing formation because of the assurance of shutting off any water section that might be penetrated.

Squeeze cementing has contributed to better completion of exploratory wells by providing reliable means of shutting off water or excess gas. When used in conjunction with gun-perforated casing or liner the operator can confine the producing section to almost any narrow limit desired. Improvement of squeeze-cementing practice will be in better control of the point at which the sheet of cement is squeezed into the formation, better technique of squeezing, and possibly development of a cement more suitable for squeezing into the formation. Many of the squeeze-cementing jobs are now no more than completing the cementing of casing that was intended to be accomplished when the casing or liner was originally cemented.

Cost of drilling a wildcat is always an important consideration in exploration for oil and gas. There is within a reasonable range a maximum depth to which a company is justified in drilling a wildcat test. At present the practical limit of wildcat drilling is generally about 8,000 or 9,000 feet for hard-rock drilling and 11,000 or 12,000 feet for soft formations. This does not mean that deeper wildcatting is not

justified, but rather that generally the cost per foot for drilling below these depths is disproportionately high compared with the cost per foot for drilling from the surface to these depths, with no probability of finding more prolific fields to compensate for the higher cost of development. Coring and drill-stem tests also are disproportionately difficult and even more disproportionately hazardous to drilling. Only a few years ago these limits were 2,000 or 3,000 feet shallower and it is certain they will be 2,000 or 3,000 feet deeper within a similar or fewer number of years in the future.

Drilling costs on wildcat wells are increased materially by coring and testing. Contributing to higher costs is the unfamiliarity of the drillers with the formations, transportation costs, and extra cost of fuel and water. The drilling rate is slower to reduce the possibility of passing up prospective producing formations. Uncertainty of how extensive a test will be required on promising indications of a productive formation is not conducive to the best progress of the well. The greatest additional cost, however, generally comes from coring, sampling, and testing, the direct cost of which is often more than half the total cost of the well. Directly attributable to such testing, but not directly charged as such, are extra trips with the drill stem, conditioning of the mud, and bad hole conditions. Core bits even when not coring will not make hole as fast as regular drilling bits. Coring contributes to greater deviation of holes, and many fishing jobs can be traced directly to bad mud conditions and bad hole conditions resulting from coring and testing. In spite of requirements for more thorough testing which increases costs, improved methods of controlling mud conditions and especially in drilling technique and equipment have been responsible for the ability to drill wells now to considerably greater depths than a few years ago without materially increasing the total cost.

Slim-hole drilling has attracted much attention in the past few years principally because of the high cost of drilling wildcat wells. From a cost standpoint slim-hole drilling has the advantage of not permitting extensive coring or testing. In many cases if wildcats are drilled with no more testing than is done in slim holes, the larger equipment can drill at a cost quite competitive with that of lighter equipment used in drilling smaller-diameter holes. Slim-hole drilling has the advantage of a lower cost for moving and daily labor, and the disadvantage of a slower drilling rate. From the cost view, the larger rig has two psychological disadvantages. There is an irresistible desire to test or core every formation that gives the slightest encouragement when the hole is large enough to permit. When a slim hole

reaches a depth at which it would be abandoned without dissent, a large hole would still be in good condition to go deeper. It is a strong-willed executive who will resist the geologist's curiosity to see the next deeper marker or prospective sand zone, and the drilling superintendent's willingness and probably his desire to make hole as long as drilling is good.

Slim-hole drilling is usually operated under a drilling program which provides for continuous operation of the drilling rig. Cost of drilling an occasional well is not comparable with the cost of a well drilled in a continuous drilling program whether it be with slim-hole or regular equipment, on prospect wells, or development wells.

Advantages and disadvantages of both slim-hole and regular equipment on prospect drilling are so numerous as to make it difficult to arrive at any satisfactory basis of comparison. Time required to drill a hole would probably provide a good rule-of-thumb comparison. A slim-hole machine would probably have advantage over regular equipment when the drilling time on a hole does not exceed 12 to 15 days. For a longer drilling time, regular equipment would probably be more economical.

Petroleum engineering has more direct application in exploration for oil and gas than is generally considered or specifically practiced. During the drilling of a wildcat well certain observations and tests are made that are indicative of the presence or proximity of oil and gas. After its presence has been proved, observations are interpreted to indicate productivity or ultimate recovery. When observations or quantified data are used to interpret probable extent of the entire reservoir, the limits of an oil and gas reservoir, or the correlation of reservoirs, they become a part of geology. Too often the geologist and petroleum engineer consider that each has his own problems which are separate. If the petroleum engineer would give more recognition to the part that sedimentation, structure, and stratigraphy play in the movement of fluids in a reservoir, and the geologist give more recognition to simple laws of physics, it would be helpful to both in their considerations of oil and gas reservoirs.

Many of the important advancements of petroleum engineering here described as applied to exploration have been made in the past 3 years or less, and are still in the early stages of development and application. Further development and more general use of methods now available and development of others may be anticipated. The continued rapid advancement of engineering in exploration for, and development of, oil and gas fields will have a parallel increase in importance to the geologist in his solution of subsurface problems.

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GEOPHYSICS[1]

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ABSTRACT

The paper points out that near-term progress in geophysical prospecting is more likely to come from further evolution of existing methods than from revolutionary new developments. Better utilization of geophysical results is likely to follow from more effective coöperation between geologists and geophysicists. For the most effective use of geophysical data, geologists will require a greater familiarity with the background and basic facts of geophysical techniques.

The paper points out that in addition to localizing acres to lease and prospects to drill, substantial contributions to general geology can and do result from geophysical work.

Reference is made to a series of simultaneous observations of the tidal variation of gravity and to the bearing of such observations on our knowledge of the general geology of the earth.

In a symposium on new ideas in petroleum exploration it may be the general expectation that the speaker will view his subject through a telescope and that he will be scanning the horizon for indications of new and revolutionary things to come. From such vantage point as I may have for vision, the geophysical branch of the prospecting art faces a period of evolution rather than revolution. In making this statement I well remember the first meeting of the Physical Society I ever attended. I saw there, many for the first time, the men whose names made history in American physics and I heard them tell each other how sorry they were for the younger generation because all the important discoveries in physics had been made and all there was left to do was to measure things out to one more decimal point. You all know what happened. Actually, physics was on the threshhold of a new era.

The present state of geophysics provides no occasion for pessimism as to its future. This is true in spite of the fact that the geochemist seems eager to drape about the head of the geophysicist the halos he claims to find adjacent to oil fields. Undoubtedly present-day equipment and techniques are well advanced and further improvements may relate largely to convenience and cost of operation. Yet in the field of better utilization there is room for substantial improvement and it is here where, in the years just ahead, the greatest progress should be made.

In mulling over the subject matter for these remarks, I was strongly reminded of an inspiring speech which I heard when a resident of Oklahoma. The orator was then professor of English at Nor-

[1] Read before the Association, April 10, 1940. Manuscript received, May 25, 1940.

[2] Gulf Research and Development Company.

man, now United States Senator from the Sooner state, his title "The Pot of Gold." Many of you must have heard it. The gist of Lee's address was that after searching far and wide, the seeker finally discovered the treasure in his own back yard. The treasure we are looking for is progress. As regards geophysics we may find it in the field of improved utilization. I believe that, although improvement may be looked for in both, geophysical techniques are more in need of better use than of better execution.

Prior to the application of geophysical methods in prospecting for oil, all the processes employed by the geologist in securing structural information had one characteristic in common. In each case, regardless of whether surface or subsurface geology or core-drilling was the method used, the rocks involved were identified by visual examination. It is not surprising, therefore, that when the gravity and other characteristically inferential geophysical methods with their dependence on the density, elasticity, magnetic, and other physical properties of rocks entered the field of prospecting, the geologist was faced with the necessity of making revolutionary changes in his mode of thinking. For this re-orientation his training had in general ill prepared him because courses leading to a degree in geology for the most part included only a minimum of physics. More recent graduates in geology are definitely in a more favorable position in this respect.

The methods of geophysical prospecting are essentially physical. The objectives only are geological. The practitioner of geophysical techniques must know geology for the same reasons that a surgeon must know anatomy. But a knowledge of anatomy, however profound, does not qualify for the practice of surgery and, by the same token eminence in geology does not necessarily imply competence in the application of geophysical techniques.

An eminent geologist who is a member of this Association has referred to geophysical methods as providing a new implementation for the geologist. This is true only to the same extent that, at an earlier day, the use of geological methods placed a new tool into the hands of the prospector. Actually the successive introduction of geological and geophysical methods of prospecting into the oil business had revolutionary consequences which went far beyond furnishing a new tool to a veteran artisan.

Both geologists and geophysicists may be, and often are, prejudiced in favor of one geophysical method and against another. Such prejudices mayhave serious consequences in sterilizing an operation which uses an inappropriate method or in opportunities lost by not

undertaking a project which clearly embodies all the elements essential to success.

All of this points to the conclusion that a proper adjustment of geological and geophysical procedures mutually and of the combination of both to the whole prospecting program has not been reached.

In general the geological information available about the structure associated with even a well developed oil field is very limited. Structural traps are ordinarily only partly filled with oil and drilling naturally does not extend appreciably beyond the productive limits of the field. Information is moreover available only to the depths actually penetrated by the wells. Although, in portraying a structure, contour maps usually go beyond the existing control, this extension is mere speculation based on general geological concepts. These generalizations may or may not be applicable and they are themselves subject to revision as more knowledge comes to hand.

In making many geophysical discoveries the operators have been content with indications that local areas are anomalous or prospective. Early seismograph reports record the discovery of a salt dome by merely stating that salt was found at a depth of X feet below the surface and by showing on the map an oval area within which the dome was presumed to lie. Nowadays it is possible to determine the shape of the salt mass by the seismic-refraction method and by the reflection method one can prepare a contour map showing the attitude of the surrounding sedimentaries against the domal mass. A project of this kind is expensive and time-consuming, but so is the drilling of a well. The daily cost of drilling a well is greater than that of operating a seismograph party, usually by a substantial margin. If on a dome prospect the same amount of money were spent in drilling one well or in doing a seismograph survey, the result would be that in one case the structure would have been tested at one point and in the other that a more or less complete structure map of the entire structure would be available, which in most cases would carry the picture to the actual limits of the structural deformation.

Many companies have made large numbers of local surveys in coastal Texas and Louisiana and have derived from them general information which has completely altered the geological concepts applicable to the area. Fifteen years ago the salt-dome belt along the Gulf Coast was regarded as a gulfward-sloping homocline pierced by numerous salt plugs. Faulting was believed to be confined to the vicinity of the domes and to be controlled by them. It is now common knowledge that a great many domes are surrounded by rim synclines in

which the sedimentaries have been depressed, many of them substantially, below their normal regional level and that as a result there are interdomal "highs" which represent areas at substantially their normal regional level and not structural uplifts at all. It is also known that some salt domes have no such rim synclines but instead have associated broad uplifts which extend for surprisingly great distances from their centers. Major synclines known to the geologist from well data are now recognized as being nothing more than the merging of a number of rim synclines into a continuous synclinal area surrounding a group of domes. It is now generally conceded that faulting is more general in the coastal area than had previously been supposed.

We have here an interesting example of how a broader picture than is likely to be obtained from drilling can profoundly alter geologic concepts. There is no doubt that some of the older coastal prospects which have not materialized were based on counter-regional dips which were actually and correctly observed, but which were incorrectly interpreted and in fact were only dips into rim synclines surrounding near-by well known domes.

From this it is obvious that in addition to localizing acres to lease and prospects to drill, the results of geophysical surveys have broader values, the recognition and utilization of which are of practical importance. I should like to recommend this area for future intensive cultivation by the joint effort of geologists and geophysicists.

Gravity instruments have been developed to such a point that only considerations of convenience and operating cost could justify much further effort toward their improvement. This being the case, one no longer has any doubts about the reality of the anomalies shown on the gravity map. But the interpretation of these anomalies is quite another matter. Although realizing that the gravity picture is correlative with the subsurface distribution of rock densities, geologists are still inclined to take for granted a conformity between gravity and subsurface structure contours. The geophysicist who handles the gravity data does not have this difficulty but is ordinarily handicapped by inadequate, if not misleading, data as to the densities characteristic of the sedimentary column in the area to which his gravity pictures relates. Knowledge of the densities may be quite as important as knowledge of the gravity picture. In this situation it is of primary importance that geologists and geophysicists develop a better mutual understanding and work together more closely.

To make this point concrete I have had prepared two figures. The first illustrates the gravity effect of the same structure at different depths of burial. It shows that the same structure may reveal itself

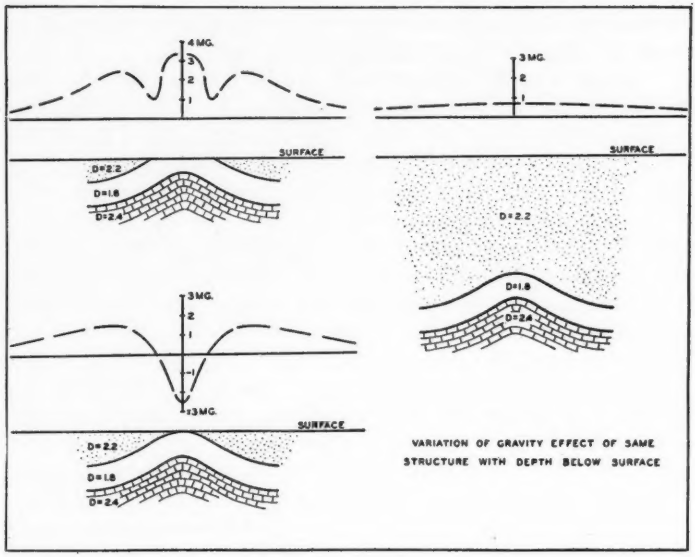

FIG. 1.—Gravity effect of same structure at three different depths of burial.

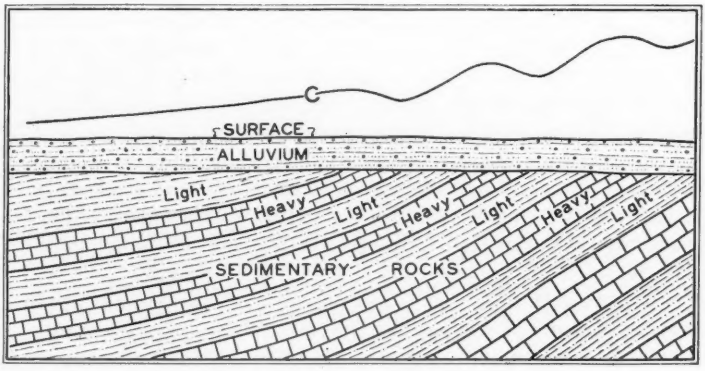

FIG. 2.—Local gravity "highs" do not necessarily connote local structures. Curve *C* shows gravity variation corresponding to geologic situation shown below it.

as a gravity minimum or maximum. Which it is depends only on the depth of burial. The second figure shows that gravity "highs" may merely indicate the location of buried outcrops.

I wish to suggest that much new pay dirt will be uncovered from old gravity maps if geologists and geophysicists will work together on this problem.

Not related to prospecting, in any event not directly, is the question of earth tides. They have interested geologists and geodesists for a long time because of the light they throw on the rigidity of the earth. We all have more or less knowledge of the tidal effects observable on the sea coast and are aware that these are due to the attraction of the sun and moon. Somewhat less familiar is the fact that similar tidal effects exist over the land masses of the earth. There is everywhere on the surface of the globe a periodic variation of gravity with time. This variation is greatest near the equator and least near the poles. In our latitudes the range of the daily variation is of the order of 0.3 to 0.4 milligal, which is just large enough so that its existence may require consideration in the procedure of making modern gravity measurements. The reason for this is that practically all gravimeters have a zero drift the magnitude of which is usually determined by returning periodically to a drift-control station. In this procedure any time variation of gravity enters the drift curve as an unrecognized component. If and when operating circumstances tend to lengthen out the intervals between drift-control observations, the tidal variations of gravity may introduce a small error in gravity-station values.

As a by-product of actual gravity surveys, members of my staff have made some observations of the variation of gravity with time at various latitudes. Figure 3 shows the variation of gravity at the northernmost point at which we have made observations, at Latitude 55° 38′ N. Figure 4 shows similar data for Latitude 9° 37′ N. Comparison of the two figures shows the anticipated variation with latitude. Figure 5 shows the record of two similar instruments at the same place, at an intermediate Latitude of 33° 11′ N. The indications of both instruments appear erratic. They are superposed in the curve *R*, after removal of the drift which was done on the basis of 24-hour running averages. One is justified in concluding that at least a part of the erratic variation, being shown by both instruments, must have been due to a corresponding variation of gravity, and that this variation is subject to local influences which are not considered by the theoretical formula.

The theoretical curves in each figure represent the tide-producing force due to the sun and moon and therefore do not include any mod-

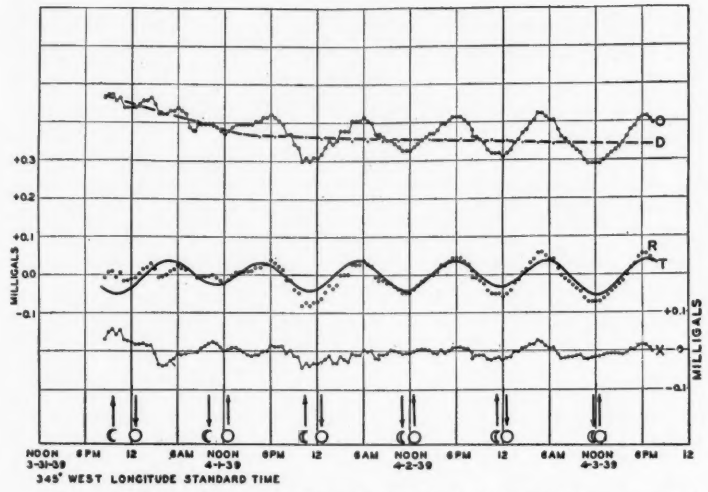

FIG. 3.—Tidal variations of gravity at Latitude 55° 38′ N. In this figure as well as Figures 4 and 5 curve *O* is plot of actual instrument observations; *D* is drift of instrument; *R* represents residual after subtracting *D* from *O*; *T* is tide-producing force computed by formulae of the U. S. Coast and Geodetic Survey; *X* is difference between *R* and *T*.

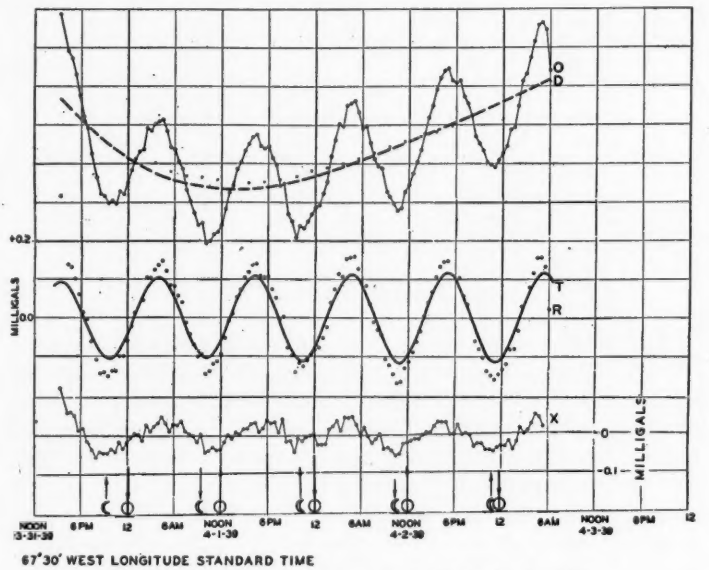

FIG. 4.—Tidal variations of gravity at Latitude 9° 37′ N.

ification which results from the tidal yielding of the earth, the nature and extent of which depend on the earth's rigidity. The departure of the observed variation from that shown by the theoretical curve must be due to the yielding of the earth as a whole and locally to the tide-producing force.

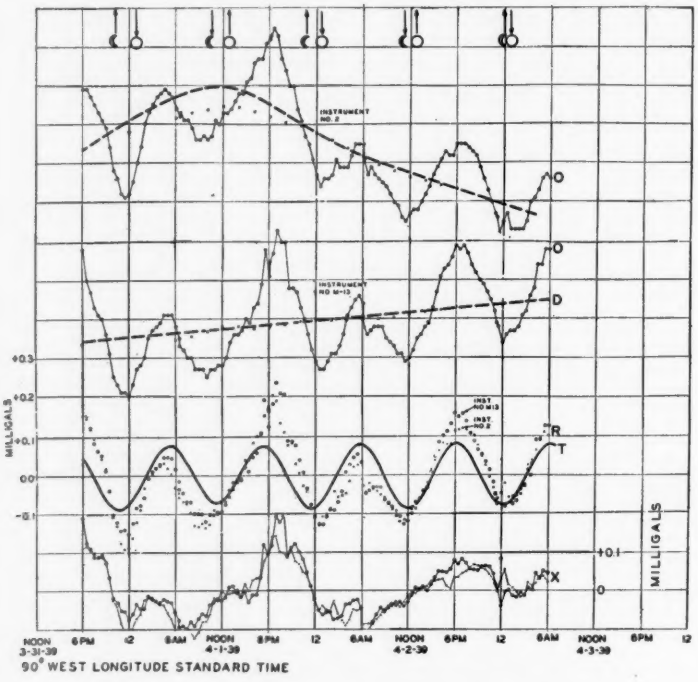

FIG. 5.—Two independent simultaneous observations of tidal variations of gravity at Latitude 33° 11′ N.

It should be mentioned that, except for differences in local time, the tidal curves of Figures 3, 4, and 5 represent observations over the same time interval though widely separated geographically.

If one is inclined to speculate on the erratic aspects of the data not explainable by instrument performance, one is tempted to suggest that perhaps the earth does not yield to the tidal forces in the manner of a perfect fluid, but rather like an area of pack ice. If the latter view is tenable, one might expect excessive local tilts and deformations of an erratic nature with corresponding variations of gravity. In that

event observations of tidal variations of gravity might be used to indicate strong and weak areas of the earth's crust and in that way make a contribution to general geology.

I am conscious of having departed from the title of this symposium if literally interpreted, but I believe that I have remained reasonably close to its spirit. All progress consists of equally important phases of advance and consolidation. After the rapid progress which has been made it is not surprising that geophysics finds itself at the moment engaged in making more solid what it has gained.

In closing I wish to reiterate that the pot of gold is in our own back yard. In order to increase the harvest it is not necessary to clear more acres. The more careful cultivation of the ground already broken may provide the most generous return for the effort made.

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WHERE WILL YOUNG GRADUATES IN PETROLEUM GEOLOGY ACQUIRE FIELD EXPERIENCE?[1]

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ABSTRACT

Opportunities for acquiring real experience in field geology, available to graduates in geology 20 or more years ago, are rarely offered by the oil companies now. The trend of petroleum geology is toward subsurface work, but proper interpretation of subsurface geological problems requires abundant field experience. Thus we are faced with a dilemma, a problem which demands thoughtful consideration, but which, in any case, may not reach wholly satisfactory solution. Toward this end, and from a broad viewpoint, we present a suggestion concerning State geological surveys.

Twenty or more years ago, the geological departments of the oil industry were actively searching for field evidences of structures, such as domes, anticlines, terraces, and faults, which might, at depth, control accumulations of oil. Dip and strike in surface outcrops, distribution of rock exposures and of soils, and topographic form were intensively studied and mapped. Field parties were numerous, and young graduates in geology had ample opportunity to acquire broad field experience under the guidance of men well trained in field geology. In this way these young men gained first-hand acquaintance with the many variations in geological structure and stratigraphy which only examination of field geology can give, and which must be understood in order logically to interpret underground conditions.

At the present time the case is very different. A large part of the area prospective for oil in the United States has been covered again and again by geologists. Relatively little field work is now in progress, and often where there is work of this kind to do it is difficult and requires men with considerable experience, rather than beginners. If the young graduate in geology is lucky he may secure a job on a field party, but usually this kind of opportunity is for foreign work. More often he must start in as a sample washer in the paleontological laboratory, or possibly as an assistant in the subsurface division of a geological department. Rarely he may be hired as a roustabout with a drilling crew, and so acquire knowledge of drilling methods. Or, less likely, he may be taken on as a scout, or he may be assigned the duty of collecting and shipping rock samples (cuttings and cores) from a well while it is being drilled.

In none of these duties does this young geologist build up a fund

[1] Read before the Association at Chicago, April 10, 1940. Manuscript received, May 25, 1940.

[2] Chief geologist, Sun Oil Company.

of experience in *field geology*. Yet he is probably headed, eventually, for office work in subsurface geology, either in building up contour and isopach maps from well data, or in correlating geophysical interpretations with geology, or in diagnosing conditions and making recommendations in connection with petroleum engineering. He may be headed for such subsurface work with little chance of acquiring the background of field experience which is so important for proper evaluation of underground geology in three dimensions.

Believing that this condition offers a real problem for our geological departments in the industry, I wrote a brief editorial which was published in November, 1938.[3] I received more than 25 replies, most of which were appreciative of the difficulty, but no one of which could propose more than a partial solution. Several of these replies showed that their authors did not understand the exact nature of the problem. Therefore, in order to make the point clear, I shall attempt to correct a few of the most conspicuous misconceptions.

One man "agreed" that young geologists do not get enough experience in watching drilling wells and in handling development programs to enable them to pass judgment on big deals, involving large sums of money. Another "agreed" that field courses offered by the universities in geology are deficient in many respects, due to shortness of available time, insufficient funds for equipment and teaching personnel, expense to students, *et cetera*. A third correspondent "agreed" that the older geologists in charge of district divisions and departments seldom have opportunity nowadays to go out in the field to brush up their knowledge. Finally, a fourth man wrote that he could not understand why, if the oil companies are so eager to hire men with broad field experience, he, who had had 20 years or more in the field, had been unable to find a job.

Now, of course, these four correspondents had an erroneous impression of the actual problem; for the problem is, not where to provide experience in watching the drilling of wells; not merely how to better university field courses in geology; not how to send the office executive geologist back into the field; and not where to find trained field men for present vacancies. It concerns providing young graduates with two or three years of practical and varied field experience in geology adequately to train them for interpreting three-dimensional, or subsurface, geology, with which they are very likely to be occupied if they receive promotion.

[3] Frederic H. Lahee, "Where Shall Our Young Graduates in Petroleum Geology Acquire Field Experience?" *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 22, No. 11 (November, 1938), pp. 1613–14.

As a matter of fact, we believe this "problem" concerns a condition which has come to stay. Less and less will the oil companies, in the ordinary routine of their geological exploration, furnish field training for the young geologists whom they employ. More and more, if these men are to gain this training, will they have to find it in lengthened and improved field courses provided by the universities. It is very doubtful whether oil companies, except in very few instances, will offer paid apprenticeships as a training ground; and it is doubtful whether, except in a few instances, oil companies will subsidize college courses in field geology. There can be no harm in trying to awaken interest in such plans for apprenticeships or for subsidizing field courses, but probably most of the improvement will have to come through aggressive steps taken by the universities which offer petroleum geology.

In closing, there is one idea which I want to present. To some it may seem somewhat far removed from our Association's interests. However, I contend that, as the largest geological organization in the world, as an association to which many classes of geologists belong, as a group from which many may eventually enter lines of geological endeavor other than petroleum geology, and as a group to which other branches will supply men for petroleum geology,—for these reasons our Association members should take an active interest in all lines of geology. We are well within our province in furthering an understanding of geology among the public. Most important is anything we can do to awaken public consciousness of the practical value of geology. This can come through efforts of our own committee on applications of geology; through an empirical threading of elementary courses in geology, offered in preparatory schools and colleges, to selected examples of the utility of geology in everyday life, rather than systematizing such courses on a genetic sequence; and through promoting a correct understanding of the proper objects, scope, and usefulness of State surveys. And when we say this, we mean in *all* practical lines —not merely in reference to oil prospects.

These ideas may sound far afield not only as applied to Association interests, but also as applied to the subject of this article; but when we carefully scrutinize and study the interrelations, possible or existing, between the occupations of our geological fraternity, the scope of the geological courses offered by our universities, and the opportunities for public service and for acquisition of experience afforded by properly functioning State surveys, I think that the pertinence of the suggestions may be evident.

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FUTURE POSITION OF PETROLEUM GEOLOGY IN THE OIL INDUSTRY[1]

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ABSTRACT

The geologist will continue to be of fundamental importance in the petroleum industry. His function, however, has changed from that of the recorder of facts as observed in the field to that of the interpreter of facts as brought to him by several exploratory specialists. His future depends on his ability to interpret facts in order to find oil. The industry is interested in the geologist insofar as he can find oil. The geologist's ability to find oil is the ability of geological speculation,—the reasonable application of all observed facts of earth science in the attempt to find oil. The greatest simple source of oil finding has been that of drilling on oil seepages, or oil and gas showings. Perhaps random drilling has been of equal importance. Geological speculation is next in importance, followed by the combined geophysical techniques. Surface geology ranks near the end of the list. But the contribution of the geologist through speculative geology has been of high value in the past, and the demand for it will become greater in the future. Therefore, the future of petroleum geology lies in better geologic training for the men who have to make the geologic speculation. They must have more exact knowledge of geologic history, geologic processes, of stratigraphy and sedimentation.

Mr. Chairman, this is not an easy subject to speak on. Three days ago I had a nicely written manuscript which I might have read glibly to you. I discarded it and made some half dozen pages of notes, most of which I think I will discard also.

The subject assigned to me by the chairman of this symposium, "Future Position of Geology in the Petroleum Industry," is an exceedingly broad subject.

Speaking strictly to my subject, I say without hesitation or qualification that geology will continue to be, as it is at present, of prime and fundamental importance in the petroleum industry. Petroleum is a mineral oil occurring in the rocks of the earth and anything bearing on its occurrence, including any and all of the successful methods of prospecting for it, is a matter of concern and consequence to petroleum geology and to the industry.

Reserves are maintained only by constant and unremitting prospecting, more pressing than for any other mineral industry, and the health of the individual, the corporation, the industry, and the nation depends on the maintenance of adequate reserves.

As Wallace Pratt has well said, "The enterprise of winning oil from the earth is essentially a geological venture," and as I said, when I addressed you 3 years ago on a similar subject, "The industry is a

[1] Read before the Association at Chicago, April 10, 1940. Manuscript received, May 25, 1940.

[2] Geologist, 611 Continental Building.

dependent function of an independent variable—exploration." One might talk all afternoon on the subject which has been assigned, but I don't want to talk that long and I am sure you don't want to listen that long.

Pratt,[3] the foremost example of the truth of his theme, has recently addressed himself to the opportunity which petroleum geology offers as a threshold to advancement into executive positions in the industry. I will limit myself, therefore, to a discussion of the future of petroleum geology and of the petroleum geologist in his art.

We can hardly examine profitably the future of petroleum geology without recognizing at once that the state of our geological knowledge varies widely for different parts of the earth. The future of petroleum geology in areas that have been subject to such intensive examination by all known methods, as have the Gulf Coastal Plain of Louisiana and Texas and the San Joaquin Valley of California, is bound to be entirely different from its future in little known areas, such as the Amazon Basin of Brazil.

We may, of course, limit ourselves to a consideration of the future of the art of petroleum geology. I should like to digress long enough to emphasize the idea that we are really working with an art. We are working with the application of the principles of the science, rather than with the particular advancement of the science of geology itself.

A year or two ago, I had occasion to attend an advisory committee meeting at Princeton, composed, about half and half, of petroleum geologists and mining geologists, to advise the university faculty upon the course being given in geological engineering. We spent half of the day in trying to decide upon a definition of geological engineering, and by two o'clock in the afternoon, not having arrived at a satisfactory definition, we went on with the rest of our work. Notwithstanding this difficulty and unsuccessful attempt to define the profession, I have no hesitation in saying that a petroleum geologist is essentially a geological engineer.

With regard to the question I have raised as to the different state of our knowledge regarding the geology of different parts of the earth, if we are going to talk about the advancement of the art from its condition of greatest development, I think we are justified in assuming that petroleum geology has reached a higher stage of advancement in the United States, in so far as general areas are concerned, at any rate, than it has elsewhere in the world. It may be that in other areas of the world specific fields are as well or better known than we

[3] Wallace E. Pratt, "Geology in the Petroleum Industry," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 24, No. 7 (July, 1940), pp. 1209–13.

know any individual field in the United States, but I think the statement I have made with regard to areas is true.

The problem becomes rather simple, then. If we consider only these areas of very advanced exploration our problem seems to be like the problem of the university professor, it is to know more and more about less and less.

Geological examination proceeds by distinct stages. In an absolutely unknown area, the first and essential step is that of general reconnaissance. For much of the earth, this has been done already and is available in published maps and descriptions. For practically all of the United States, such material is easily available. The petroleum geologist is likely to make this highly desirable reconnaissance, however, even if good information is available, since it will serve to give him better understanding of such information and to fix the geography of the area in his mind.

Rarely, the results of such reconnaissance may be sufficient to lead to the discovery of an oil pool. The surface expression of a Kettleman Hills or a Salt Creek is such that he who runs may read. The structure in which the pool of the Ganzo Azul is being developed in eastern Peru was first recognized by Moran from the air. I think he was returning from another piece of work, and was not even engaged in geological reconnaissance.

The chief and expected result of such reconnaissance, however, is that of enabling the petroleum geologist to decide upon the areas to be examined further and the methods to be used in such examination.

Occasionally, reconnaissance may show that the area under consideration is such that further surface work is not justified. Much of the Llanos of southern Venezuela is an example of such area.

Normally, however, the sequence of methods of examination to be used is likely to be that of reconnaissance geology, detailed geologic mapping, magnetic or gravimetric mapping, or both, and core-drilling or seismic-reflection examination. Crudely, this is about the historical order of development of the various techniques of examination, but the controlling reason for the order of selection is economic and not historical. The order is one of increasing exactness and of rapidly increasing cost.

I have described our prospecting effort, on various past occasions, as a series of more or less separate and distinct techniques, rather than as one long, slowly developing art. Each valid technique comes to general acceptance and application slowly and peaks rapidly, carries on for a few years, and then becomes relatively unimportant as it sinks to a residual value for any specific area. The usefulness of a

technique becomes exhausted for any specific area when all of the interesting part of the area amenable to its use has been thoroughly examined. In other words, a technique exhausts its usefulness by being used. Perhaps a few concrete examples will give a better understanding of this concept than further abstract discussion.

The technique of prospecting by drilling on oil seepages was practically exhausted for California in the few years that were required to drill practically all known seepages. Likewise, the technique of prospecting topographic mounds and oil or gas seepages in the flat lands of the Texas and Louisiana Coastal Plain was exhausted within 2 years after discovery in 1901 of the Lucas gusher, when practically all such known mounds had been explored. Surface geology became an important guide to prospecting in Oklahoma and Kansas about 1913, but its usefulness was of only residual importance after the early twenties.

The outstanding example, perhaps, of all individual techniques of prospecting—outstanding because of its historic importance and compactness—is the refraction survey of the Gulf Coast of Texas and Louisiana for the relatively shallow salt domes. Neglecting the early experimentation which was more of historical than practical importance, this campaign really began in early 1924, and it was concluded by late 1930. The entire coast had been examined, not once, but several parts of it, to my own knowledge, as many as six and seven times, by the use of this technique. The technique sank into disuse after that except for sporadic applications and some experimental use, and no attempt was made to apply it in other areas of the United States to which it was not suited.

In his examination of the surface, the geologist was limited to the accident of surface outcrops. Only the south end of the Tonkawa anticline, for instance, could be mapped from the surface. Its more important and more interesting north end was buried in the alluvium of the broad flood plain of the Salt Fork of the Arkansas River. Even in less exaggerated examples, the surface geologist will remember that the validity of his interpretation of structure often depended on the correctness of his correlation of sandstones which were exasperatingly without character.

The first solution of this difficulty was digging pits, the creation of artificial exposures, and one of the special forms of trenching, a procedure followed for centuries by the mineral prospector. This technique was followed with notable success by the geologists of the Dutch-Shell group in the early oil exploration of the East Indies, in some of the early work in Venezuela, and to a much less degree by

the geologists of the Mexican Eagle in the Isthmus of Tehuantepec, Mexico. The method was but little used in the United States.

Core drilling was the next method used to get a clear map of structure. Its first notable success was in mapping the northern extension of the Tonkawa field, Oklahoma, and its most widespread use was probably in mapping the structure of western Kansas.

The introduction of core drilling as a technique of geological mapping was a notable event in the history of oil prospecting. It gave to geological mapping a degree of precision which it had not previously had, but, more than that, it was the first experience of the industry with a prospecting technique substantially more expensive than the simple hire and expense of the field geologist. The favorable results secured undoubtedly did much to prepare the industry for the acceptance of the hazards of the even more expensive campaigns of geophysical work soon to follow.

One of the fathers of mineralogy is reported to have dismissed his students with the patriarchal injunction, "Go, my sons, buy stout shoes, climb the mountains, search the valleys, the deserts, the seashores, and the deep recesses of the earth." This bold admonition, which has been followed in tenor by teachers of the geological sciences down to the present, is good for relatively unknown areas, but I submit that for most of the highly explored oil regions of the United States we are definitely out of the "stout shoes" period.

For every day that our future petroleum geologist, working in such centers as Houston, Los Angeles, or Tulsa, spends in his "stout shoes" making first-hand observations of consequence, he is likely to spend weeks in the office considering electrical logs, micro-paleontological reports, or geophysical data. Practically all of the factual data with which he now deals are secured for him by specialists and his function has changed from that of field observer to that of student and interpreter.

This is no attempt to indict or discredit surface geology. I would point out its limitations, emphasize the fact that in many areas its value is exceedingly small, and that in all developing oil regions there comes a time when its usefulness is almost negligible. It never was of real value in the Gulf Coast—I refer to the Coastal Salt-dome region. Petroleum geologists in that area, for the score of years which intervened between the campaign of wildcatting which followed the Lucas discovery at Spindletop and the introduction of geophysics, searched for direct indications which they occasionally found and which rarely resulted in the discovery of a new dome, or searched for the diagnostic topographic mounds. practically all of which were already

known and prospected. Their most fruitful work was that of guiding the continued exploration of known domes.

The real campaign of surface work in Oklahoma and Kansas, regions where it was most widely accepted by the industry as a guide to prospecting, was only of 10–15 years' duration. Surface geology is similar to the other prospecting techniques, in that for any single area, continued and active use exhausts its usefulness.

I was very much interested in Dr. Lahee's remarks. He confirmed an idea that I, myself, have had and that is that in these highly explored areas, where the petroleum geologist of the future is dependent on the interpretation of data secured for him by specialists, the use of surface geology as a practical field measure is of practically no consequence whatever. I also agree with Dr. Lahee as to the desirability and necessity of training in field geology as an educational measure.

You may have noticed that I have not yet referred to subsurface studies, and may have wondered why I have neglected so important a phase of the work of the petroleum geologist. I regard subsurface studies, to the degree that they are not speculative, as the reference against which the results of all other methods of investigation must check. The study of subsurface is the one continuing technique of the industry and the one which will outlast all others. It is a running speculation, corrected and revised as often as additional data from drilled wells are available. I might be slightly facetious and say that the invention of the electric eraser was probably the greatest single advancement in it. It is concerned with structure; the nature, extent, and distribution of sands and formations; the existence and extent of unconformities; and the nature and extent of oil, gas, and water showings. It is of great secondary or reconnaissance value in affording clues to be resolved by other methods.

As I have said before, petroleum geology is a form of geological engineering and, as such, is subject to the limitation of cost. A special paper might be given on that subject alone. I will content myself with merely outlining three different aspects of cost to be considered: (1) the total cost; (2) the time or rate of expenditure; and (3) the cost per unit of area of work—that is, the cost per acre or square mile.

The volume and type of work to be done may control the selection of the technique of examination to be used. On the other hand, the amount of money available for work may be the factor controlling selection of technique. In many cases even the rate of expenditure controls.

Probably the best and most outstanding example of the results of

the different phases and effects of the cost problem is the change in the cost of oil finding. The cost of oil finding, since the introduction of geophysical methods, has resulted in great increase in total expenditure but the cost per barrel has been reduced, I should say, for average good practice—not average practice, because the statistics upon which to base such an opinion are not available—from a minimum of 25 cents a barrel to a maximum of 10–12 cents a barrel. These figures result from considerable investigation. This cost has been achieved by the introduction of methods which, in total, as I have just noted, have been extraordinarily expensive.

Dr. Weatherby has recently estimated the cost of all the geophysical work in the United States at approximately 200 million dollars. I, myself, have made something of an investigation of the subject, and my estimate is somewhat less than his. I think we can safely say that between 150 and 200 million dollars has been spent for the actual technique of geophysical investigation alone, without taking into consideration such costs as option bonuses, or the cost of lands.

I might also add that according to any estimate I can make, this is probably several times as much as has been expended on all geological work, although geological work extends over a greater length of time.

The use of the geophysical methods, neglecting their early experimental history, began with the initiation of the hectic search for salt domes in the Gulf Coast area by refraction and torsion-balance surveys in early 1924, with the surveys of Oklahoma by the reflection method in 1928–30, the reflection surveys of the San Joaquin Valley of California in 1933, the reflection-dip shooting and continued torsion-balance surveys of the Gulf Coast in 1932, the reflection surveys of Illinois in 1935, of northern Louisiana and southern Arkansas in 1936, and with the intensive examination by reflection surveys and gravity meter of Mississippi and Alabama which reached a state of intense activity during the present year and is still under way.

If we had more time available, I might enter into this question of coöperation of geophysics and geology. Personally, I am skeptical enough to believe there is no more sense in regarding geophysics as a distinct science by itself, than there was for a consideration of the introduction of the plane table as marking the beginning of a distinct science.

The value of all forms of geophysical work, up to the present at least, may be rated as being directly proportional to the degree of definiteness with which we are able to interpret the physical measurements in terms of structural geology. So far as I am concerned, I am

willing to leave it there. On this basis, in ascending order of values, I would rate the various methods as follows: (1) magnetic; (2) electrical; (3) gravitational; and (4) seismic.

The gist of this whole talk, it seems to me, has been that the problem of prospecting is and will always continue to be a geological problem. It is a problem of rational interpretation in terms of geology of physical results. I think perhaps, sometimes, the geophysicists feel we don't give them enough regard and respect for their high competence. I am sure that I do.

Actually, what is being done, for example, in seismic work, which is by far the most widely used and most successful of all the methods, is the securing of point-by-point elevation determinations on whatever formation can be worked; that is, whatever formation happens to have the physical characteristics which will give reflection points which can then be contoured and interpreted in terms of structural geology. We work on the assumption that this particular formation is parallel to or that its relation to the sand, which is expected to be the oil sand, is or can be determined. That is all we ever did with data secured in the field with a plane table.

I think the geophysicists are one of the most highly trained groups of technical men in the oil industry, but beyond the taking of these precise physical measurements in which the operating geophysicists are skilled comes the matter of interpretation which seems to me to be solely and simply a matter of geological probability.

I have pointed out to you that the modern geologist, the geologist in foreign work, is likely to go through any of these various stages which the requirements of the area which he is examining call for, but the geologist in the areas of most advanced exploration, such as the Gulf Coastal Plain or California, has become very strictly an interpreter.

As I have emphasized in this talk, he no longer goes out into the field and makes direct observations. He doesn't need a note book, unless he wants to record his line of thought. He no longer has any factual data to record. All of his data is determined for him by specialists. His rôle is reduced, or elevated, as you want to consider it, to that of interpreter. It seems to me that it follows without argument that the future of his ability, that his future success in his chosen profession, must depend on his ability to interpret.

Within recent years I have been trying to assemble enough data to make a quantitative study in terms of oil reserves discovered, of the results of prospecting by all of the various techniques and methods. Very early in this study, I found that I was in a good deal of

trouble with those successes which I intended to ascribe to geological work.

There are two types of geological work. There is the classical geological structural hunting, which is probably regarded by the general public as the common type of prospecting. That is work where the geologist goes into the field and finds a well defined structure exposed on the surface. The structure is drilled, and, if successful, results in the discovery of a subsurface structure which, in turn, may be oil-bearing.

Actually, in talking to the Dallas Geological Society some 2 months ago, in part because I believed it—I wasn't entirely convinced, but more than anything else I really wanted to see if somebody would disprove it to me—I stated that of the 100 most important oil fields in the United States, there were not more than 10 that could be reasonably outlined from the study of the surface geology, and I gave six examples that I thought could be reasonably outlined and waited for somebody else to find the four that would complete my exception, and the fifth that would disprove it. The statement was not enthusiastically received, but I don't remember that anybody made any contribution, any addition to the six fields which I had given.

In studying this question of prospecting I did find, however, that there is a great deal of successful prospecting which I would attribute to what, for lack of a better term, I will call geological speculation. One of the outstanding examples, it seems to me, was the discovery of the Huntington Beach oil field which Mr. S. H. Gester has described in, I think, Volume 8 of the *Bulletin* of the Association. He goes into great detail in outlining the geological reasoning on which the location of the initial well was drilled. This I regard as being geological speculation of the highest order. While I am not so well acquainted with the line of speculation which resulted in the location of the discovery wells in the deep fields off Coalinga, I should think that it also was speculative geology of the highest order.

The oil industry is not particularly interested in geology or geologists, physics, or geophysicists as such; it is interested in all of these various efforts in the degree that they can help to find oil.

I should say right now, without having completed my investigation, that the greatest single source of oil finding, with the possible exception of random drilling, has been that of drilling on oil seepages or oil and gas showings. I should say, if that stands first, casual and random drilling stands second. I should say that geological speculation stands third, and if we wish to combine all of the various geophysical techniques, I should say that, all together, they stand fourth. I

should think that perhaps surface geology, as such, is rated pretty well toward the end of the list, but the contribution of the geologist through what I might call speculative geology has been of exceedingly high value in the past, and the demand for it will become much greater in the future.

Therefore, in my opinion, the future of petroleum geology lies in better geologic training for these men who have to make the speculation. They have got to have a more exact knowledge of geologic history, geologic processes, of stratigraphy and sedimentation, if you please, than they have had in the past.

When geology was being introduced into the oil industry, it met with a great deal of objection on the part of the so-called practical men; it wasn't practical. As an actual matter of fact, no man ever drilled a wildcat oil well who wasn't speculative. If it wasn't for the speculative instinct which guides the oil industry, we wouldn't be here to-day. The only difference between the old, so-called practical man and the geologist was that the practical man was an unrestrained and untrammeled speculator. He had no particular rules to guide him. He knew nothing of what had happened elsewhere, and any of you who have met practical men in the field—I am sure all of you have—know how weird and wild some of the ideas they can have may be. The only advantage the geologist has as a speculator is that he is or should be a trained observer, and he is limited and restrained in his speculation by his knowledge of the nature and extent of geological processes.

The man who is the best geologist in the future, all other things being equal, ought to be the most successful prospector in the industry.

DISCUSSION

QUESTION.—Upon what basis did you evaluate the relative merits of geophysical methods; accuracy alone, or were time, cost, and other factors taken into account?

DEGOLYER.—As I stated in my talk, upon the degree of definiteness with which we are able to interpret physical measurements in terms of structural geology.

R. W. PIKE.—When you say that one of the most important rôles of a geologist is to interpret geophysical data, do you mean that: (a) the geologist accepts the picture as created by the geophysicist and studies that, or (b) the geologist builds the picture from the observed data of the geophysicist?

DEGOLYER.—More nearly (b), I should say. Interpretation must be in terms of rational geology. After long-continued work in a single region, particularly if it is simple, interpretation becomes fixed. A 0.30 second lead in the old refraction days on the Gulf Coast was pretty good evidence of the existence of a salt dome and all of the geologists in the world couldn't improve the interpretation. For that particular region, such a lead was diagnostic. On

the other hand, in the shooting of the Lucien pool in Oklahoma, knowledge could only be properly interpreted in the light of the geologic pattern of pre-Pennsylvanian structure.

QUESTION.—Some geologists have expressed the opinion that there are many shallow pools, 7,500 feet or less, still to be found, some of which may be large. They may be found in areas already studied by well known techniques. By what method or methods should these areas be re-examined for shallow oil?

DEGOLYER.—This is too vague a question to answer with other than vague advice. I should say by subsurface studies and by geophysical work where the geologist searching for the trap definitely directs or interprets the work of the physicist, *if useful results can be secured.*

E. E. ROSAIRE.—An interpreter from French to English should know both French and English. If a geologist is to interpret geophysics, shouldn't he know geophysics? Geology means earth science. Why restrict the term geologist to one who only describes the earth, and deny it to the geophysicist, who measures the earth and its properties?

DEGOLYER.—I will reply to Dr. Rosaire's first question by the age-honored method of asking its converse. If a physicist is to interpret geophysics, shouldn't he know geology? The truth of the matter is that real geophysicists are as scarce as hen's teeth. The art of determining geological structure by the use of the highly technical, precise measurements of the physicist is extremely young. Until we have men who are skilled in both geology and physics, we will not have real geophysicists. To-day, Dr. Barton's old classification still holds—we have physicist geophysicists and geologist geophysicists. The one group, mostly operative geophysicists, are, for the most part, highly trained physicists, some of whom have slowly acquired through long experience a knowledge of geology in very special areas but which does not include enough of the rudiments of the science to enable them to pass a test in elementary geology. On the other hand, we have the geologist geophysicist, trained and experienced in petroleum geology, for the most part office men, and whose knowledge of the science of physics is of about high school grade. There are not more than enough exceptions to the foregoing generalization than are regarded normally as necessary to prove the rule. Doubtless, in the future happy state, we will have geophysicists trained and skilled in both sciences. They will laugh at our present argument as at the foolish bickering of incompetents.

I accept Dr. Rosaire's analogy as to the interpreter, merely pointing out that we are still waiting for an interpreter who speaks both languages equally well and that literal translations are generally pretty crude affairs.

As to the second question, I believe that Dr. Rosaire has slipped over to the broadest of definitions for geophysics—literally earth physics. We are talking about applied geophysics—applied to the problem of structure-hunting as it has been developed to date and a much narrower subject. You will get my point by attending a meeting of the American Geophysical Union. Does our applied geophysicist "measure the earth and its properties?" In an exceedingly limited sense. So does the man who sells a load of sand and the child who recognizes salt by its color and taste.

I have no desire to restrict the use of the term, geologist. I only suggest that he study geology; at least he ought to know enough about his science not to define himself as "one who describes the earth."

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SYMPOSIUM ON GEOCHEMICAL EXPLORATION

GEOCHEMICAL PROSPECTING FOR PETROLEUM[1]

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ABSTRACT

Case treatments are presented or pointed to in the literature which include examples of prospecting by refraction fans, a geoelectrical method (Eltran), and chemical analyses of soils, soil gases, and ground waters.

These type geophysical and geochemical anomalies are associated with producing structure, which, in several cases, display only low relief at considerable depths, where the anomalous data represent modifications of shallow sediments undeformed by the underlying structure.

These illustrations indicate that the column of sediments over a petroleum accumulation displays properties which differ from those of the adjacent sediments of the same geological age. As a result of these differences in properties, observed even where no observable structural deformation has taken place in the affected sediments, a dynamic rather than a static conception of a petroleum accumulation is indicated. A description and a discussion follow of a working hypothesis which has been proposed to account for these geochemical manifestations of a petroleum accumulation.

Geochemical prospecting takes for its objectives the recognition of the geochemical manifestations of a petroleum accumulation, and their interpretation in terms of their origin, of the petroleum accumulation itself, by means of the local and regional geology.

GEOCHEMISTRY OF A PETROLEUM DEPOSIT

The mining geologist would consider himself seriously handicapped were his interest and study restricted to the geology of an ore deposit, for its geochemistry is required in the solution of the problems with which he is confronted.

Yet, in exploration for petroleum, we tacitly consider a petroleum deposit as an inert and static mass, similar to a coal seam in place. Such a viewpoint is furthered by consideration of a stripper field, where work must be done to extract the petroleum from its reservoir. However, a different and a dynamic perspective is forced upon one who observes or attempts to control a wild well, which handles tons of rock and water like confetti at Mardi Gras, and which bends alloy steel as a child bends warm taffy.

Granting the relatively impermeable nature of the shales and limestones of the typical sedimentary column, still one can hardly conceive that any such formation is *absolutely* impervious, particularly in view of the underground rock pressures and concentration gradients existing and maintained in a petroleum accumulation, which continuously force the component hydrocarbons into and through its sedimentary environment. Under pressure, hydrogen leaks

[1] Read before the research committee, April 9, and before the Association, April 10, 1940, at Chicago. Manuscript received, May 25, 1940.

[2] Subterrex, 701 Waugh Drive.

through a steel bomb. In the case of a petroleum accumulation under normal rock pressure, *some* effusion of hydrocarbons must take place into and through even a relatively impervious sedimentary environment. The amount and the rate of effusion are of secondary importance, for, over the tremendous span of geologic time, the chemical and physico-chemical effects of minute but never stopping leakage will have added up to totals of more than appreciable magnitudes.

GEOCHEMICAL PROSPECTING

We now can recognize two phases in geochemical prospecting, the megascopic phase and the microscopic phase.

MEGASCOPIC GEOCHEMICAL PROSPECTING

The Drake well probably can be considered to have initiated organized prospecting for petroleum. The first prospecting technique developed was that based on the search for, and the recognition of, visible evidence of oil and gas, a rational and direct approach, which, it has been said,[3] was responsible for the discovery of more petroleum than any other prospecting technique developed to date. Megascopic geochemical prospecting played an early and important part in the search for petroleum in California, Pennsylvania, Illinois, the Gulf Coast, Mexico, Persia, and, in fact, in most of the important petroleum-producing provinces of the world.

MICROSCOPIC GEOCHEMICAL PROSPECTING

The first step toward microscopic geochemical prospecting probably was the early work of H. E. Minor[4] on the ground waters in the Gulf Coast about 1920–1925. Among other phenomena, he discovered, and recognized as such, a definite geochemical anomaly in the form of a buried saline where, 10 years later, the Tomball oil field was discovered. At the time, Minor's colleagues did not grasp the significance of these data, for, being two-dimensional, they did not display the convexity indicative of structure. In view of the then recognized need for new prospecting techniques, it is more than probable that the pursuit of this geochemical beginning would have led to the development of microscopic geochemical prospecting. That such a sequence would have been natural is shown by developments in the mining field. There the mining geologist went from his descriptive geology to the geochemistry of the ore deposit, and *then* to its geophysical recognition and exploration.

[3] E. DeGolyer, "Future Position of Petroleum Geology in the Oil Industry," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 24, No 8 (August, 1940), pp. 1389–99.

[4] H. E. Minor, "Oil-Field Waters of the Gulf Coastal Plain," *Problems of Petroleum Geology* (Amer. Assoc. Petrol. Geol., 1934), pp. 891–93.

It is somewhat surprising that more progress has not been made in microscopic geochemical prospecting, for, in spite of his predispositions toward structural prospecting, the geologist finds geochemistry a field which, in importance, is second only to his descriptive geology.

As a matter of note, the geological literature is rich in geochemical studies and data.[5] Scattered through this literature, and through unrecorded individual experience, there are many instances, previously unrelated, which now can be recognized as geochemical manifestations of a petroleum deposit.

In our investigations and research, we have discovered and recognized other phenomena which also are truly part of the geochemistry of a petroleum deposit. Undoubtedly, other similar phenomena remain to be discovered in this relatively untrodden field. Indeed, geochemical prospecting is like a recently opened mine, for the investigator can hardly turn around without striking pay dirt. Unfortunately, that condition has led to a great deal of apparent confusion in the field, for new phenomena and brash hypotheses may be given undue importance, just as, in a mine, a promising "color" may lead the miner temporarily astray from the pursuit of the primary vein.

GEOCHEMICAL MANIFESTATIONS OF PETROLEUM ACCUMULATION

The geochemical manifestations of a petroleum accumulation fall into two broad classes, the near-surface effects and the near-deposit effects.

The near-surface phenomena are two-dimensional, are of interest primarily in prospecting along the surface, and apparently do not permit the (linear) consideration of depth.

On the other hand, the near-deposit phenomena permit some consideration of depth, are of interest primarily in geochemical well logging, and contribute data which will be of vital importance in studies directed at the history of the accumulation and the origin of petroleum.

NEAR-SURFACE GEOCHEMICAL MANIFESTATIONS OF PETROLEUM ACCUMULATION

These near-surface effects are of peculiar interest in that they are manifested as localized patterns in the near-surface sediments, even when associated with petroleum accumulation enclosed within deep-seated and low-relief traps. That is, these geochemical anomalies indicate the presence and the areal extent of the petroleum accumulation from which they originate.

The hazard associated with their use in prospecting is that there

[5] See partial bibliography at end of this article.

appears to be no obvious (linear) relationship between the magnitude of these geochemical effects and either the depth to the accumulation or the relief of the associated trap. As long as the nature of these geochemical anomalies and their lack of depth or structural indication were not understood, their past use as prospecting objectives has been limited to spasmodic trials. Our predisposition to structural

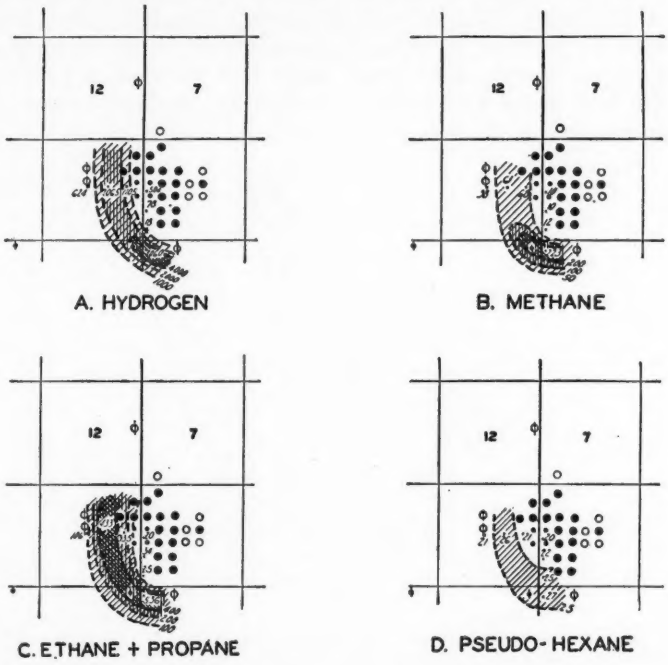


FIG. 1.—Gaseous constituents by soil analysis. Small symbols indicate wells drilled before, and large symbols wells completed after, soil survey. From Leo Horvitz, "On Geochemical Prospecting," *Geophysics*, Vol. 4, No. 3 (July, 1939), Fig. 1, p. 216.

prospecting has led us, in the past, to misinterpret these magnitudes as manifestations of the depths to the associated traps, whereas they possibly are related more closely to the past or present magnitude of the accumulation, and to the passage of geologic time.

When compared with the adjacent sediments of like geological age, the column of sediments over a petroleum accumulation has been modified in several ways. The following case treatments[6] illustrate

[6] Note that the halo or annular pattern is indicated in other measurements besides soil analysis.

some, but by no means all, of the various forms in which geochemical manifestations of a petroleum deposit have been observed by measuring the properties of the overlying sediments.

GEOCHEMICAL MEASUREMENTS

SOIL AND SOIL-GAS ANALYSES

The effusion of hydrocarbons has been diminished across the bedding planes of the sediments above the accumulation itself. This difference results in the typical hydrocarbon halo found by analyses of the near-surface soil,[7] which shows that the effusion over the petroleum deposit is less than that through the immediately surrounding sediments of the same geologic age (Figs. 1 and 2).

FIG. 2.—Soil analysis for ethane and propane. Small symbols indicate wells drilled before, and large symbols completed after, soil survey. Station interval is 500 feet. From Leo Horvitz, "On Geochemical Prospecting," *Geophysics*, Vol. 4, No. 3 (July, 1939), Fig. 3, p. 219.

The halo pattern was indicated but not recognized in the earlier technique of soil-gas analysis[8] for significant hydrocarbons.[9] The failure to recognize this typical and significant pattern undoubtedly was primarily responsible for the relative lack of success encountered by the early investigators in that field.

[7] E. E. Rosaire and Leo Horvitz. U. S. Patent No. 2,192,525.

[8] G. Laubmeyer. U. S. Patent No. 1,843,878.
L. Horvitz, "On Geochemical Prospecting," *Geophysics*, Vol. 4, No. 3 (July, 1939), pp. 210–35.

[9] E. E. Rosaire, "Discussion and Communications," *Geophysics*, Vol. 4, No. 4 (October, 1939), pp. 300–06.

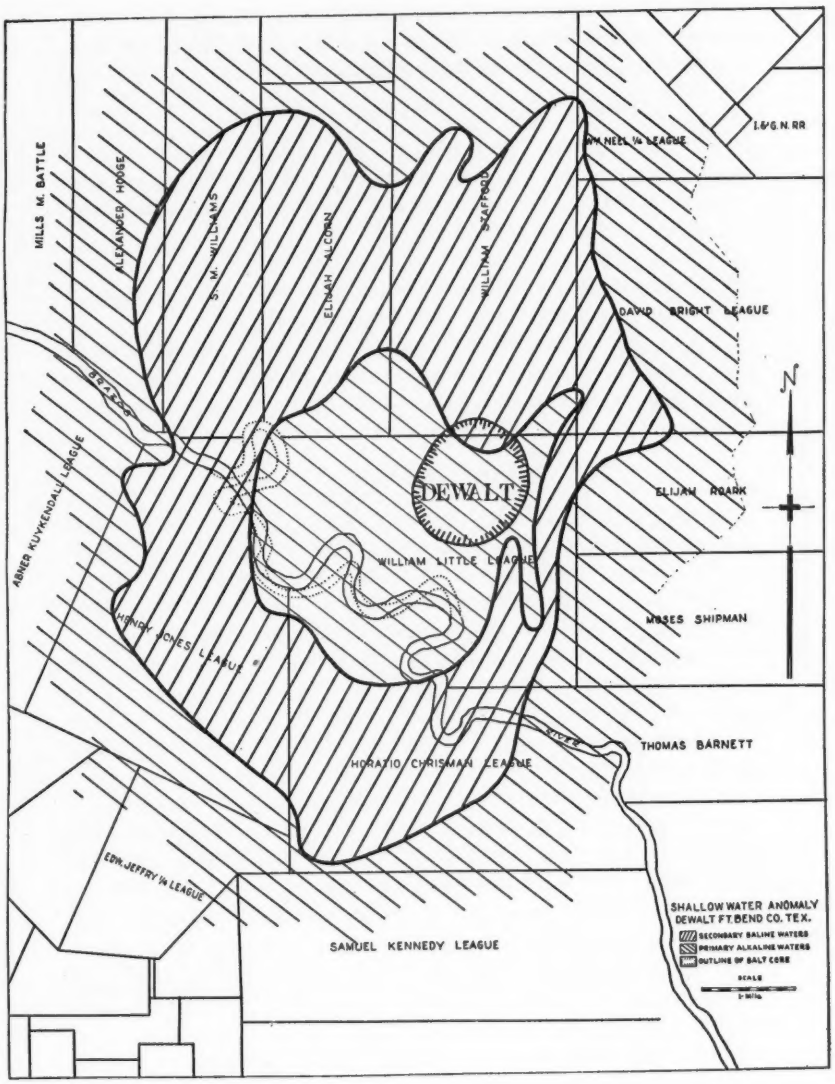


FIG. 3.—Shallow-water salinity anomaly. From H. E. Minor, "Oil-Field Waters of the Gulf Coastal Plain," *Problems of Petroleum Geology* (Amer. Assoc. Petrol. Geol., 1934), Fig. 4, p. 898.

However, at least some of the earlier prospectors using megascopic geochemical prospecting in the Gulf Coast had recognized the halo or aureole pattern displaced by significant gas seeps.[10]

INORGANIC ANALYSES OF GROUND WATERS AND SOILS

The shallow ground waters are modified, giving rise to the mineralized springs and buried salines observed at shallow depths over oil fields, such as that observed by Minor[11] several years before the Tomball oil field was discovered by the drill.

Figure 3 shows the salinity anomaly which Minor observed at the Sugarland oil field, and which is reproduced from Minor's paper, previously mentioned. Again, note the halo pattern.

Many analyses for other organic and inorganic soil constituents show significant patterns which bear much the same relationship to underlying petroleum accumulation as do the more familiar halo patterns of the significant soil hydrocarbons.[12]

GEOPHYSICAL MEASUREMENTS

Several geophysical methods have been used widely in structural prospecting, and each of them has shown the same history, as follows.

After some preliminary skirmishing, the proper tactics were developed for the geophysical method in question. Thus, though tried initially in profiling, the proper tactics for the refraction seismograph was the "fan," which was particularly applicable to the search for piercement-type salt domes in the Gulf Coast Embayment. Again, the proper objective for the torsion balance was the gravity minimum[13] generally associated with that same type of geological structure in the same general area.

Once the appropriate tactics or objectives were recognized and proved, exhaustive application of the method followed, continuing until all, or nearly all, of the "findable" types of such structures were discovered. Eventually, diminishing returns set in, and the technique finally entered the "non-decisive" stage,[14] leaving in its wake, how-

[10] Wallace E. Pratt and L. P. Garrett, personal communications. Mr. Garrett has pointed out that his map of the Goose Creek oil field, *Geology of Salt Dome Oil Fields* (Amer. Assoc. Petrol. Geol., 1926), p. 547, was drawn on just such an annular distribution of gas seeps.

[11] H. E. Minor, *op. cit.*

[12] E. E. Rosaire, *The Handbook of Geochemical Prospecting* (1939).

[13] In the earliest torsion-balance trials, the objectives were gravity maxima. Two or three years passed before the recognition became general that the gravity maximum was a special case, and the gravity minimum the general case.

[14] E. E. Rosaire, "On the Strategy and Tactics of Exploration for Petroleum—I," *Geophysics*, Vol. 3, No. 1 (January, 1938), pp. 35–37.

ever, marginal and submarginal anomalies of the same general type as those on which the technique scored its successes, but which the technique, unaided, could resolve no further.

As a rule, those remaining marginal and submarginal anomalies far outnumber the anomalies (of the same kind but of generally greater magnitude) which have been confirmed by the drill. Thus, a few years ago, the estimate was made that more than 400 gravity minima remain unproved in the Gulf Coast, several times the number of piercement-type salt plugs known to exist in the same area. A similar situation exists there in refraction prospecting, for a large number of refraction anomalies remain unexplained, totaling at least twice the number of piercement-type salt domes in the general area.

The writer explains this situation by postulating the presence of two effects, one purely structural, the other purely geochemical. The structural effects ordinarily show a maximum intensity above the *center* of the *structure*, and the geochemical effects ordinarily show a maximum intensity over and around the *edges* of the *accumulation*.

In the case of a piercement-type salt dome, both effects could be and in many places were present. In such a case, the magnitude of the structural effect ordinarily was several times the magnitude of the geochemical effect (the latter with an origin in an associated petroleum accumulation).

Obviously, the structure of greater relief had a double chance of being observed as a large magnitude anomaly, or, conversely, a large magnitude anomaly was more probably a shallow structure. Therefore, successful tests of the more obvious Gulf Coast geophysical anomalies generally (but not everywhere) resulted in the discovery of piercement-type salt domes. The tests applied (the reflection seismograph and the drill) were primarily tests for structure, *and only secondarily for the presence of petroleum*. That is, if a major refraction "high" (0.4–0.5 second) was tested by the drill, and no evidence found of structure, the geophysical anomaly was charged off as an error, and the prospect then dropped from the active list.

The ensuing process was that of elimination on structural standards alone, so that many marginal refraction and gravity anomalies remained unproved and so inexplicable on the basis of structure alone. However, not a few recent Gulf Coast discoveries have been found to be associated with one or both of these types of marginal geophysical anomalies which, because of their association with low-relief structure, probably are geochemical in nature.

The writer then postulates that the many remaining marginal geophysical anomalies in the Gulf Coast (which to date are *structurally*

unproved) probably represent cases in each of which the magnitude of the structural effect is less than the magnitude of the geochemical effect due to an associated petroleum accumulation.

The familiar objection that too many such exist (to be indications of undiscovered petroleum accumulations) is not valid, for the higher-relief structures are the exceptions, and the lower-relief structures are the rule, and, so, more numerous. That situation is indicated in any petroleum-producing province where a high density of subsurface information is available. In Oklahoma, structures with relief comparable with that at Oklahoma City are far outnumbered by the "pimple" structures which, for the past several years, have been the prospecting objectives of that province.

Some of these marginal geophysical anomalies, which are believed to be primarily geochemical in origin, are described in the following sections on refraction anomalies and gravity anomalies.

REFRACTION ANOMALIES

In refraction-fan exploration, the seismic travel times could be (significantly) shortened in either of two ways (of course, operating either singly or together, according to the structural and accumulation conditions). One of these was purely structural, when the top of the salt plug was at a depth so shallow that the characteristic "salt leads" or forerunners could be observed on the records. These were relatively low-amplitude impulses arriving appreciably (0.3–0.8 second) ahead of the normal sedimentary impulses. (These lower amplitudes resulted from the greater speed of travel in the salt, together with the approximately circular cross section of the plug, a combination which, in effect, acted as a concave lens does to light waves.[15]) This technique was that which was used in the refraction-fan exploration for piercement-type salt domes in the Gulf Coast from 1923 to 1930.

An example of such "structurally" shortened travel times occurred in the case of the Vermilion Bay salt dome.[16]

The other effect present was the geochemical shortening of refraction-travel times which resulted from the lateral modification of sediments which were not structurally displaced. These geochemical shortenings of refraction-travel times ordinarily were of the order of magnitude of 0.1 to 0.3 (rarely 0.4–0.5) second. The magnitudes of

[15] Donald C. Barton, "The Seismic Method of Mapping Geologic Structure," *Geophysical Prospecting, 1929* (Amer. Inst. Min. Met. Eng., 1929), p. 595.

[16] E. E. Rosaire and O. C. Lester, Jr., "Seismological Discovery and Partial Detail of Vermilion Bay Salt Dome, Louisiana," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 16, No. 12 (December, 1932).

these geochemical-refraction anomalies bear no apparent (linear) relationship to the depth or to the relief of the associated structure.[17]

Case treatments of such geochemically shortened travel times are shown in Figure 4, the Turtle Bay oil field, Chambers County, Texas, and in Figure 5, the North Crowley oil field, Acadia Parish, Louisiana. Both of these fields are associated with traps which are low in relief and are relatively deep-seated (at least when compared with piercement-type salt domes).

The refraction anomalies shown are the interpretations (of the original refraction data) which were made prior to 1930, and which were then considered sufficiently large in magnitude to be marked for future attention. Note that, in both cases, these (geochemically) shortened travel times are associated with the *edges* of the producing area rather than with the producing area itself. On the other hand, the *structurally* shortened travel times, as at the Vermilion Bay salt dome,[18] occurred over the *structure*. (The variations in travel times are displayed in the same manner as those for the case of the Vermilion Bay salt dome. That is, the shortenings of travel times are plotted away from the shot point, according to the time scale indicated, and the lengthening of travel times are plotted toward the shot point, along the arc representing normal arrival times.)

These two case treatments explain one of the early and most outstanding failures of the refraction seismograph in the Gulf Coast.

Prior to the development of refraction-fan tactics, the refraction seismograph was used as a pure structure-finding technique. Seismic profiles were used for making depth estimates, and, in the Gulf Coast, led to the recognition of so-called "semi-consolidated highs." At the time, no consideration was given to the possibility that lateral changes in the shallow sediments could exist, that is, that there could be variations not reflected in the structure of the shallow beds. Obviously, if such lateral changes were encountered, the shortened travel times were misinterpreted as purely structural changes, thus leading to the localization of spurious structures.

The first seismic crew in the Gulf Coast was that operating for the Marland Oil Company about 1923, relying on structure-finding by seismic profiles. At the time, Alexander Deussen was directing those field operations, and, on the basis of favorable surface indications, he had isolated and had leased a prospect on the Brazos River, in Fort Bend County, Texas. After mapping the area by seismic profiles, a

[17] E. E. Rosaire, "Shallow Stratigraphic Variations over Gulf Coast Structures," *Geophysics*, Vol. 3, No. 3 (1938), pp. 96–115.

[18] E. E. Rosaire and O. C. Lester, Jr., *op. cit.*, p. 10.

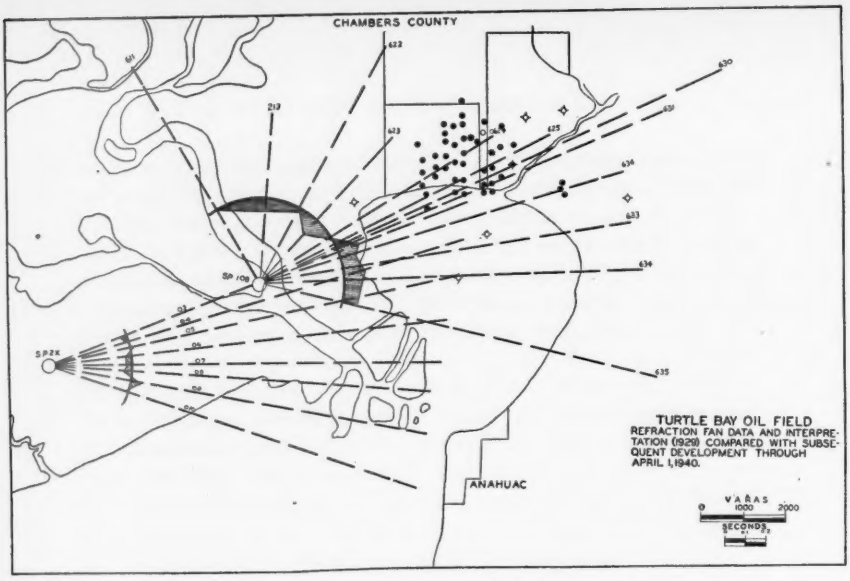


FIG. 4.—Refraction fans, Turtle Bay oil field, Chambers County, Texas.

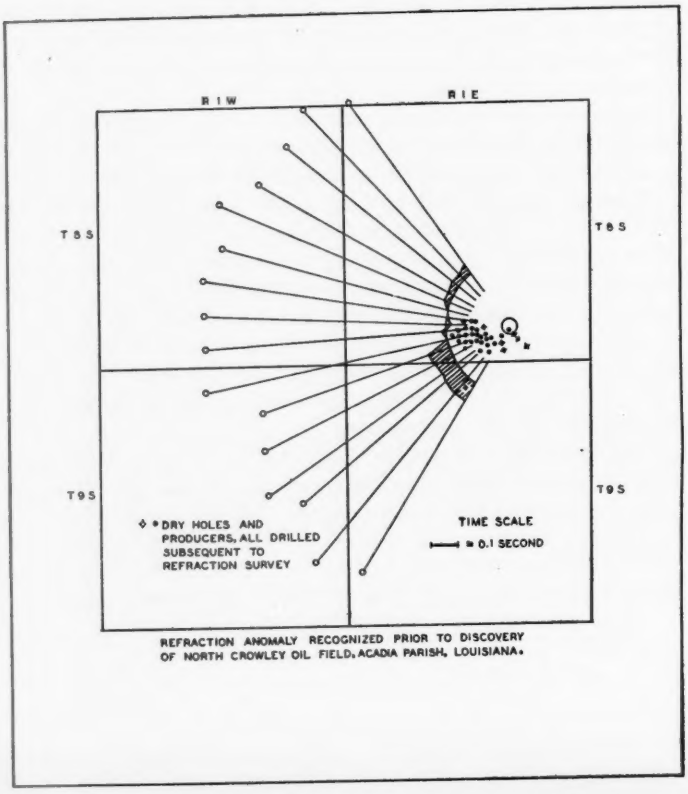

R 1 W
R 1 E
T 8 S
T 9 S
DRY HOLES AND PRODUCERS, ALL DRILLED SUBSEQUENT TO REFRACTION SURVEY
TIME SCALE
= 0.1 SECOND
REFRACTION ANOMALY RECOGNIZED PRIOR TO DISCOVERY OF NORTH CROWLEY OIL FIELD, ACADIA PARISH, LOUISIANA.

FIG. 5.—Refraction fan, North Crowley oil field, Acadia Parish, Louisiana.

"semi-consolidated high" was recognized by the refraction crew, and a well was drilled there by the Marland Oil Company. The well was dry and abandoned at 4,510 feet, to all intents and purposes condemning the prospect.

We are now in position to recognize the excellent quality of Deussen's surface prospecting, for that early lease block comprised about 75 per cent of what is now the Thompsons oil field. The dry hole, which apparently condemned the prospect, is located close to the (probable) edge of the producing area as we know it to-day, that is, on on *annular* refraction anomaly which probably is geochemical in origin, but which was erroneously interpreted as due to structure.

These case treatments illustrate how such a misinterpretation (as a spurious structure) of geochemically shortened travel times could lead to the conditions which actually occurred in the early seismic prospecting at Deussen's 1923 surface prospect, now the Thompsons oil field.

Such a misinterpretation of geochemically shortened travel times occurs in either refraction or reflection (whether dip or correlation) mapping if no consideration is given to existing lateral (geochemical rather than structural) changes in the seismic speeds characteristic of the near-surface sediments.

These case treatments, and others which are at hand, illustrate how the annular or halo pattern may be displayed in the (geochemically) anomalous seismic properties of the sediments overlying a petroleum accumulation.

GRAVITY ANOMALIES

The torsion-balance anomalies observed at Sugarland, Sour Lake, Fannette, and elsewhere are typical illustrations where the gravity minima are, without question, due to the relatively shallow salt plug.

On the other hand, the localized gravity minima which contributed to the discoveries at the Eureka and Turtle Bay oil fields illustrate cases where the gravity anomalies could not have been structural in origin, for the associated structures are known from drilling to be low in relief at depths of 7,700 and 5,500 feet, respectively. Although such significant and localized gravity minima have been assumed, generally, to be due to deep-seated salt plugs,[19] they are more reasonably explained as gravitational expressions of geochemical anomalies in the near-surface sediments which owe their origin to the petroleum accumulation itself.

[19] Ed J. Hamner, "Amelia Oil Field, Jefferson County, Texas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 23, No. 11 (November, 1939), p. 1637.

In at least one case the writer has seen a Gulf Coast gravity anomaly which took the form of an annular gravitational maximum rather than a simple minimum. While that anomaly is not yet validated by production, it is associated with other geochemical data of apparent significance, and so probably is associated with a low-relief accumulation. The writer is of the opinion that such a gravitational expression (annular) of a geochemical anomaly[20] is more common than is generally realized, and that detailed gravitational exploration of the multitudinous unexplained marginal Gulf Coast gravity anomalies will confirm that conclusion. Such detailed gravitational studies have been materially facilitated by the recent substitution of the gravity meter for the torsion balance.

INDURATION ANOMALIES

The drillers of a generation ago, certainly in the Gulf Coast (similar phenomena are reported to have been observed in Pennsylvania),[21] reported "dome digging" in wells favorably located on structure, and softer drilling in the case of unfavorably located wells. The writer has discussed this phenomenon previously,[22] and has little more to add at present, except to call attention to the previous observation and description of an indurated sandstone at a shallow depth over the Raccoon Bend oil field.[23]

GEOELECTRICAL ANOMALIES

In the early days of geophysical prospecting for petroleum, geoelectrical methods were tried in structural prospecting. Because of the inherent difficulties in getting large enough power sources to permit profiles of appreciable extent (and so, supposedly, penetration), trials of geoelectrical methods in petroleum prospecting were limited and spasmodic. Geoelectrical prospecting remained confined to mining geophysics and to shallow structural hydrological studies, except for a secondary prospecting technique (after the drill), in the form of the electrical logging introduced by Schlumberger.

In 1936, the results of some electrical transient[24] (Eltran) investi-

[20] The annular pattern may also be expected to be shown in geomagnetic surveys under similar conditions.

[21] Leigh Taliaferro, personal communication.

[22] E. E. Rosaire, "Shallow Stratigraphic Variations over Gulf Coast Structures," *Geophysics*, Vol. 3, No. 3 (1938), pp. 96–115.

[23] L. P. Teas and C. R. Miller, "Raccoon Bend Oil Field, Texas," *Gulf Coast Oil Fields* (Amer. Assoc. Petrol. Geol., 1936), p. 680.

[24] L. W. Blau. U S. Patent No. 1,911,137.

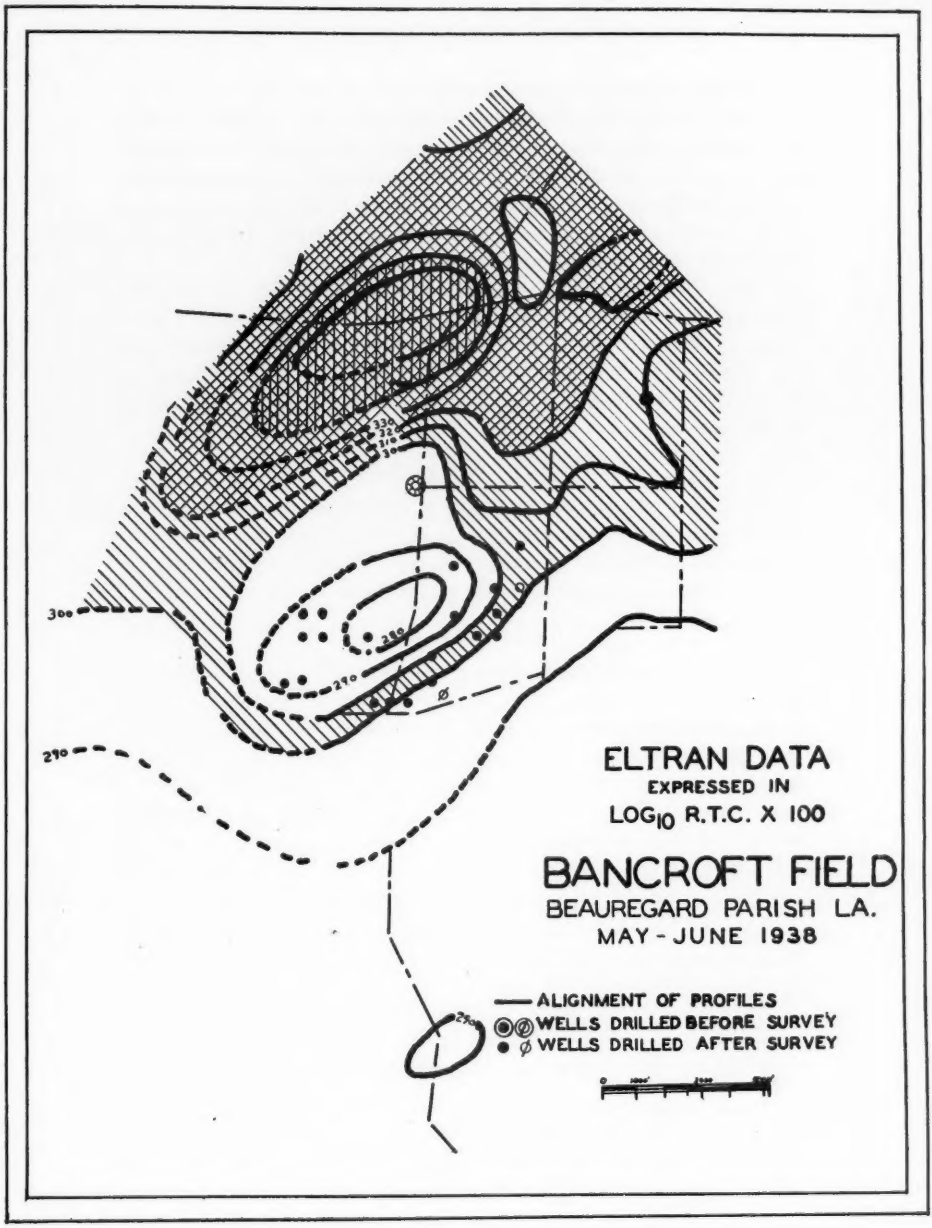


FIG. 6.—Eltran map, Bancroft oil field, Beauregard Parish, Louisiana.

gations were reported,[25] which showed a definite anomaly over an unidentified but deep-seated and low-relief Gulf Coast oil field. Further investigation along these lines has led to the geoelectrical recognition and measurement of significant geochemical anomalies. Figure 6 shows such a geoelectrical anomaly at the Bancroft oil field, Beauregard Parish, Louisiana, a deep-seated and low-relief structural accumulation on the downthrown side of a fault.

Similar concentricity in geoelectrical patterns (i.e., around the edges of accumulation) have been observed elsewhere in the Gulf Coast, in South Texas, in Illinois, in California, and in the Permian basin, even in the case of low-relief traps (including sand lenses and overlaps), but *only* when such traps are associated with petroleum accumulation.

OTHER ANOMALIES OF GEOCHEMICAL ORIGIN

The sedimentary column above a petroleum accumulation has been measured in several other ways, and other anomalous properties have been observed. At present, these types of measurements and the resulting data are not available for publication.

HALO PHENOMENA

In the literature[26] and in unrecorded discussion, reference has been made to a "halo theory" supposed to have been postulated by the writer and his associates. Attention is called to the fact that no such "halo theory" has been advanced in any such fashion. On the contrary, the writer and his associates have reported halo phenomena observed experimentally in soil analyses.[27] The case treatments and references here presented show that the halo pattern also has been observed and indicated by megascopic geochemical prospecting, in soil-gas and salinity studies, in geoelectrical measurements, in refraction prospecting, and has been suggested in gravity prospecting. Later in this paper, a *hypothesis* is presented which has been *postulated* to account for such *experimental observations*.

Attention is called to the localized nature of these geochemical and geophysical anomalies, which can be attributed only to near-surface modification of the sediments. That calls for a revision of some of our

[25] Louis Statham, "Electric Earth Transients in Geophysical Prospecting," *Geophysics*, Vol. 1, No. 2 (June, 1936), pp. 271–77.

[26] A. J. Teplitz, discussion of paper entitled "Geochemical Prospecting" by Leo Horvitz, *Geophysics*, Vol. 4, No. 3 (July, 1939).

[27] E. E. Rosaire, *op. cit.*, p. 11.

Leo Horvitz, "On Geochemical Prospecting—I," *Geophysics*, Vol. 4, No. 3 (July, 1939), pp. 210–28.

present conceptions, as in the case of the localized gravity minima which still are Gulf Coast prospecting objectives. Heretofore it has been assumed that these owe their origin to deep-seated salt plugs. It should be obvious that a deep-seated origin could *not* give rise to localized surface anomalies, unless the law of inverse squares has been repealed.

NEAR-DEPOSIT GEOCHEMICAL MANIFESTATIONS OF PETROLEUM ACCUMULATION

Although we have had several more or less satisfactory ways of determining, predicting, or estimating the depth to particular geologic horizons, we never have had a prospecting technique which made it possible to estimate the depth to a *petroleum accumulation.* As long as we recognized that structure was a necessary but not a sufficient condition for petroleum accumulation, dry holes were shrugged off because "oil was where we found it." That problem arose only when we could not do more than grin and bear it after a later and luckier prospector had offset our dry hole and drilled deeper for a discovery well. As Mark Twain said of the weather, we have talked about the "farmer's sand,"[28] but never have done anything about it.

Hydrocarbon halos of the same order of magnitude have been found associated with production at 1,500 feet and with production below 13,000 feet. If, as is reasonable to suppose, petroleum accumulation exists at even greater depths, then that, too, can be expected to be displayed geochemically to about the same order of magnitude in the near-surface sediments. So, with the advent of microscopic geochemical prospecting, the problem of the depth to the petroleum accumulation becomes, for the first time, of prospecting as well as of practical importance.

Geochemical well logging appears to be a first and necessary step in the solution of that fundamentally important problem. At present progress has been made to the extent that the possibility of accumulation can be estimated in the 500 to 1,000 feet of untested sediments ahead of the bit. Also, since the geochemical influence of a petroleum deposit extends laterally as well as vertically beyond the limits of production, the possibility of accumulation ¼ to ½ mile laterally from a dry and abandoned well can be estimated from its geochemical well log.

This is some progress, at least, for it permits rational coring programs, and, even though a wildcat test may be abandoned, the geochemical log contributes important evidence as to the validity of the

[28] "Farmer's sand." The saturated oil sand which, as every farmer knows, underlies his land, and above which, a few feet too shallow, every dry wildcat is abandoned.

prospecting conclusions upon which the location was made. Further, "slim-hole" prospecting is now applicable to the search for deep-seated, low-relief, and even stratigraphic accumulation.

As used at present, geochemical well logging is a prospecting rather than an assaying technique, for the better sample media seem to be cuttings or cores from the less permeable formations rather than from the potential reservoir rocks, such as the sands. In the passage of geologic time, equilibrium has been established in the sedimentary column, and, when brought to the surface, the hydrocarbon concentrations in the relatively impermeable shales are better indices of the existing subsurface concentrations than are the hydrocarbon concentrations in the more permeable sands, from which evaporation can and does take place more readily.

Obviously, if the sampling is very close to the petroleum deposit, the magnitude of the geochemical effects should be relatively large. For that rather obvious and certainly logical reason, geochemical well logging has yielded unanticipated phenomena which are not only of great interest, but also are, without question, of great economic importance.

In considering geochemical well logs, one must keep in mind that they are made up by the analyses of cuttings secured in routine drilling. Perhaps the surprising thing is that data such as these can be secured by the analyses of such sample media, in view of the possibilities of contamination by circulating drilling mud, by cavings from higher up the hole, and by free metal from bit wear. These are prospecting data of a new type, and are not a substitute for other recognized types of well logging.

In geochemical well logging, the more significant concentration depth patterns appear to be, first, those of the petroleum hydrocarbons, and, second, that of the hydrogen evolved from the sediments in the routine analytical procedure. As these studies continue, we expect to discover that other constituents will display significant concentration depth patterns.

Hydrogen is evolved during the analyses of many cuttings and cores. The origin of this evolved hydrogen is not clear at the present time. Some of it is free in the sediments, some of it originates in free metal from bit wear, but some hydrogen unquestionably is significantly evolved during the analysis. Lacking a satisfactory explanation for its (significant) origin, at the present time we consider this evolved hydrogen as a measure of some sedimentary constituent, as yet unidentified, which appears to be part of the geochemistry of a petroleum accumulation.

Although the data at hand are none too complete, they indicate that the zone of geochemical influence extends less than a mile outside of the limits of production, for we have at least one case of a dry hole barely ¾ mile from edge production, which showed hydrocarbon and evolved hydrogen logs of negligible concentrations (Fig. 12).

Figures 7–14 illustrate actual geochemical logs made up by the analyses of the ordinary cuttings secured from drilling wells. Reading from left to right in each of these, the individual logs are, respectively, evolved hydrogen, total hydrocarbons, methane, "gas" hydrocarbons (methane through butane), "distillate" hydrocarbons (pentane through about undecane), sand (acid insoluble), carbonates, sulphates, and halides (undifferentiated chlorides, bromides, and iodides), expressed in per cent concentrations by weight of the particular constituent referred to the weight of the (cutting) sample. As experience develops in geochemical well logging, other constituents will be found to occur in significant concentrations.

WORKING HYPOTHESIS

INTRODUCTION

Our approach to geochemical prospecting has been entirely experimental. Such an attack is always costly, both in time and money. As progress is made, the sins of commission are emphasized by *ex post facto* judgment, outglaring the at least comparable sins of omission.

Be that as it may, the fact remains that a hypothesis, let alone a theory, for geochemical prospecting was not obvious, in spite of the wealth of (previously unrelated) geochemical data and studies in the (petroleum) geological literature. For some time, then, the crying need in geochemical prospecting has been for a satisfactory working hypothesis which not only would permit the correlation of the data at hand but also would aid in the direction of further effort.

Such a working hypothesis must be considered as open to extension, revision, or even replacement in the light of new evidence. At the present time, the limited use of geochemical prospecting follows primarily because of the lack of general interest in exploration, and secondarily because of obstacles which are largely psychological in nature. This hesitancy on the part of the industry to make use of techniques which are not generally understood is quite understandable, for we recognize that most of the failures attributed to microscopic geochemical prospecting have followed, to a material degree, from the lack of complete understanding of the techniques and their utilities on the part of those of us who have been interested in their application to date.

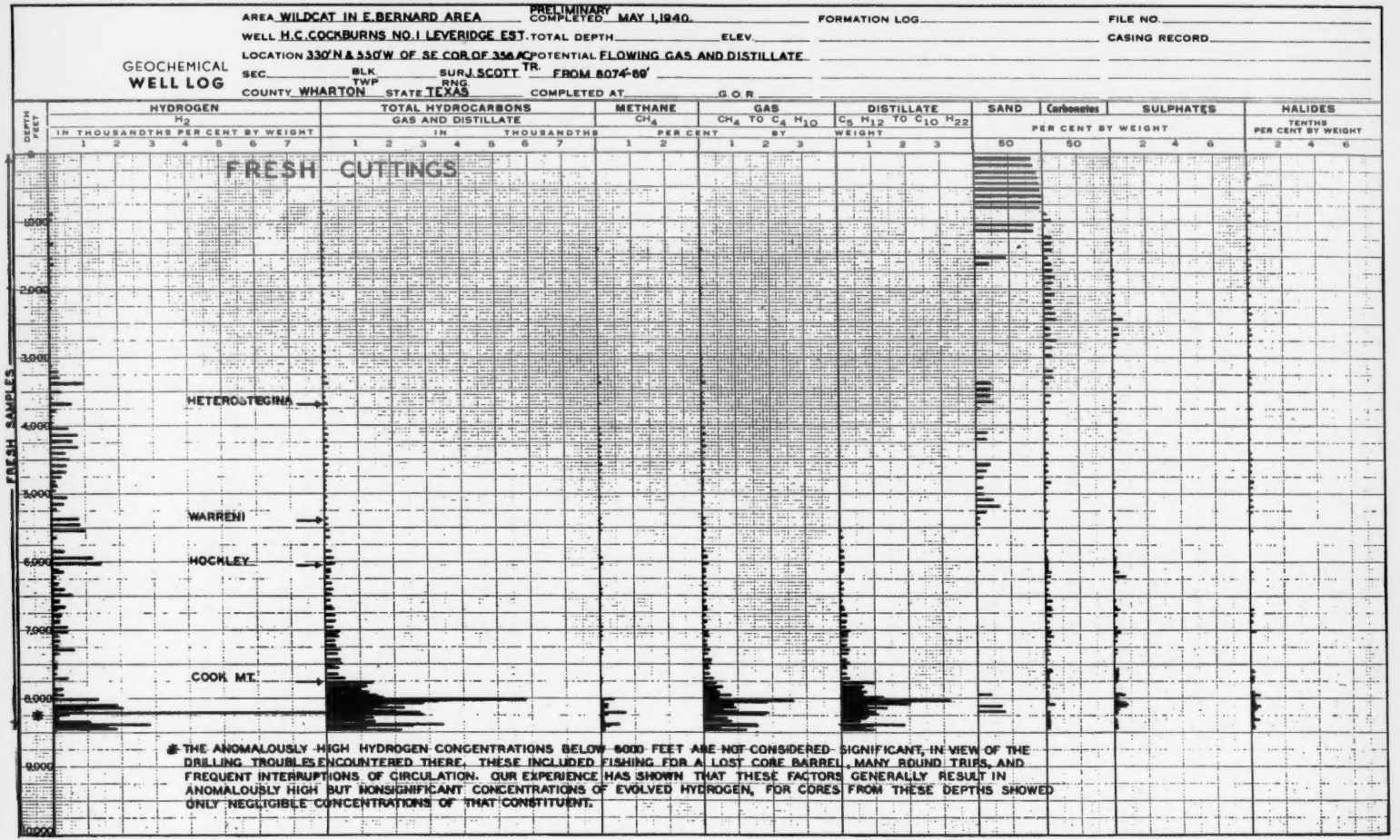

GEOCHEMICAL
WELL LOG
AREA WILDCAT IN E.BERNARD AREA
PRELIMINARY
COMPLETED MAY 1,1940.
FORMATION LOG
FILE NO.
WELL H.C.COCKBURNS NO.1 LEVERIDGE EST. TOTAL DEPTH ELEV.
CASING RECORD
LOCATION 330'N & 550'W OF SE COR OF 356 AC POTENTIAL FLOWING GAS AND DISTILLATE
SEC. BLK. SUR J. SCOTT TR. FROM 8074-89'
TWP.
RNG.
COUNTY WHARTON STATE TEXAS COMPLETED AT G.O.R.
HYDROGEN
H_2
IN THOUSANDTHS PER CENT BY WEIGHT
TOTAL HYDROCARBONS
GAS AND DISTILLATE
IN THOUSANDTHS
METHANE
CH_4
PER CENT
GAS
CH_4 TO C_4H_{10}
BY
DISTILLATE
C_5H_{12} TO $C_{10}H_{22}$
WEIGHT
SAND
Carbonates
SULPHATES
HALIDES
PER CENT BY WEIGHT
TENTHS
PER CENT BY WEIGHT
DEPTH IN FEET
FRESH SAMPLES
FRESH CUTTINGS
HETEROSTEGINA
WARREN I
HOCKLEY
COOK MT.
* THE ANOMALOUSLY HIGH HYDROGEN CONCENTRATIONS BELOW 8000 FEET ARE NOT CONSIDERED SIGNIFICANT, IN VIEW OF THE DRILLING TROUBLES ENCOUNTERED THERE. THESE INCLUDED FISHING FOR A LOST CORE BARREL, MANY ROUND TRIPS, AND FREQUENT INTERRUPTIONS OF CIRCULATION. OUR EXPERIENCE HAS SHOWN THAT THESE FACTORS GENERALLY RESULT IN ANOMALOUSLY HIGH BUT NONSIGNIFICANT CONCENTRATIONS OF EVOLVED HYDROGEN. FOR CORES FROM THESE DEPTHS SHOWED ONLY NEGLIGIBLE CONCENTRATIONS OF THAT CONSTITUENT.

FIG. 7.—Geochemical log, discovery well, East Bernard field, Wharton County, Texas.

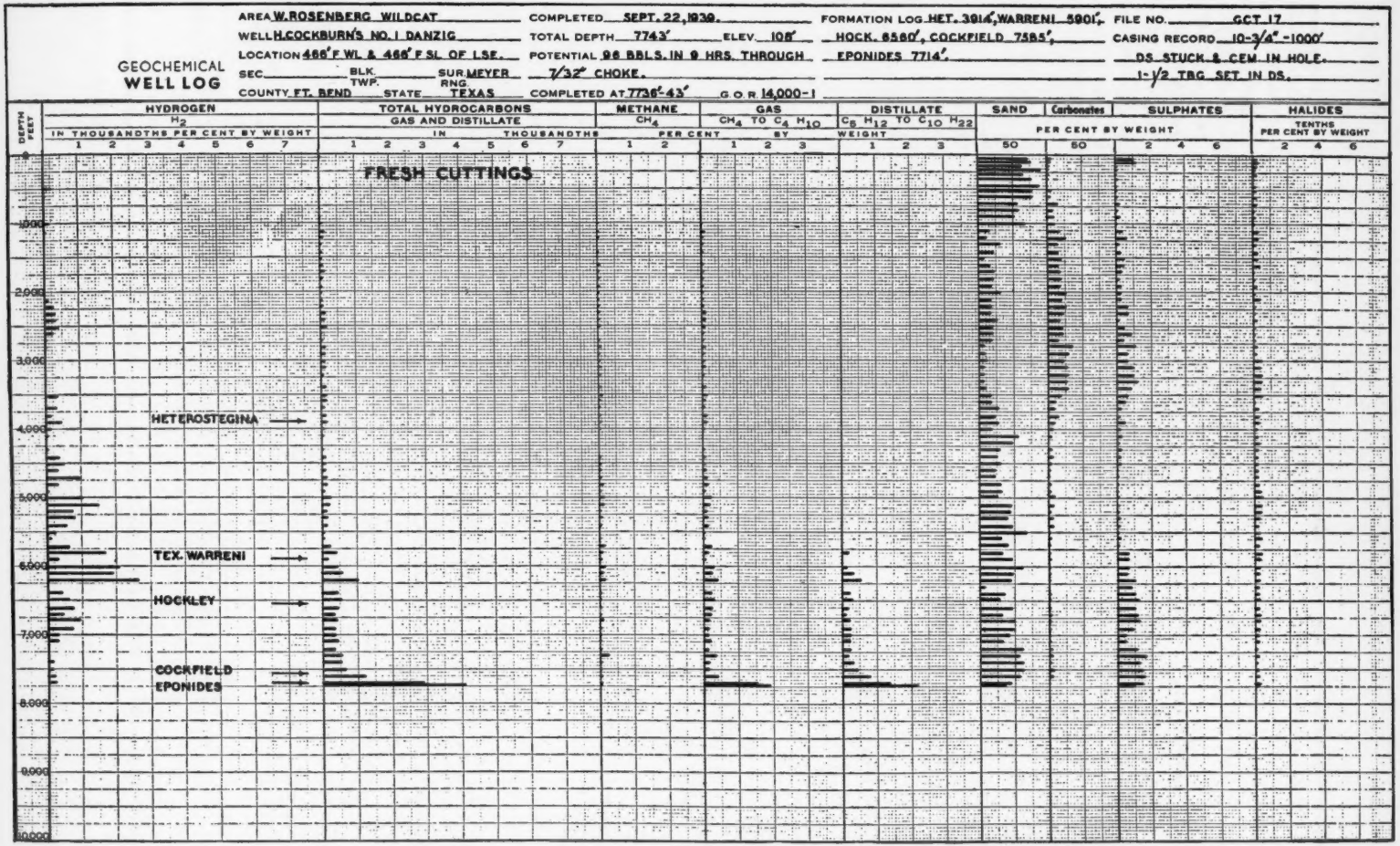


FIG. 8.—Geochemical log, discovery well, Rosenberg field, Fort Bend County, Texas.

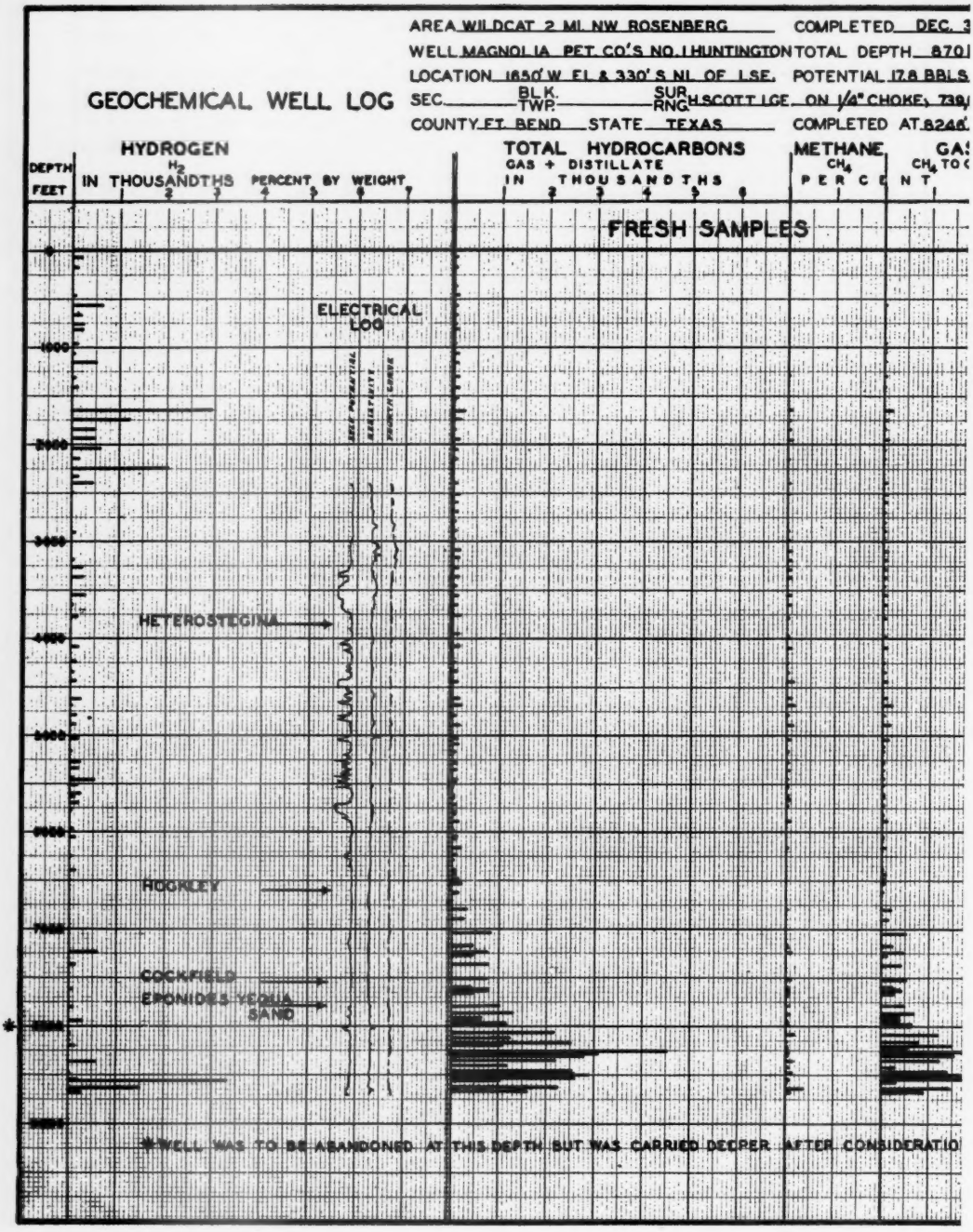
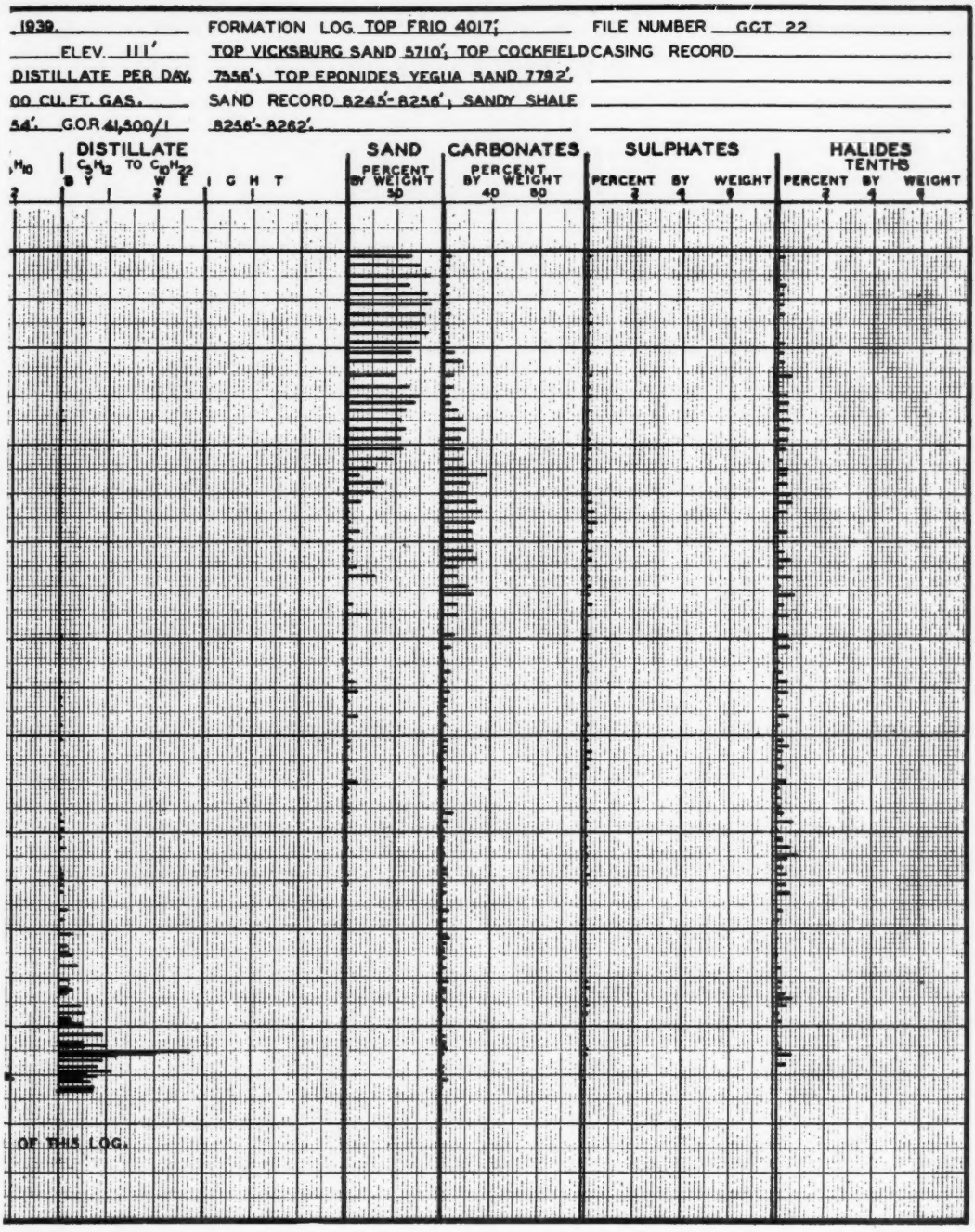


FIG. 9.—Geochemical log, "temporary"



producer, Fort Bend County, Texas.

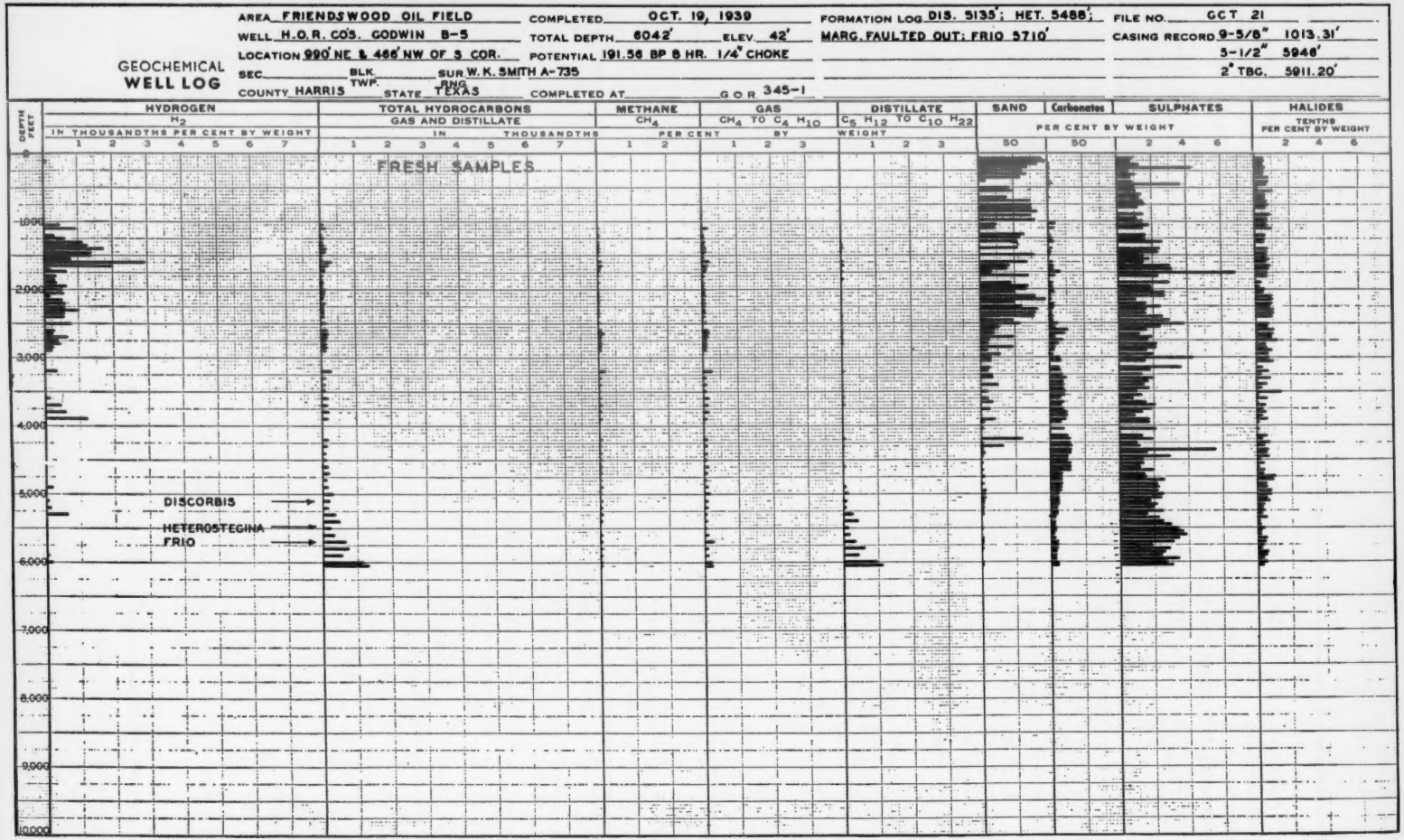


FIG. 10.—Geochemical log, producing well, Friendswood oil field, Harris County, Texas.

FIG. 10.—Geochemical log, producing well, Friendswood oil field, Harris County, Texas.

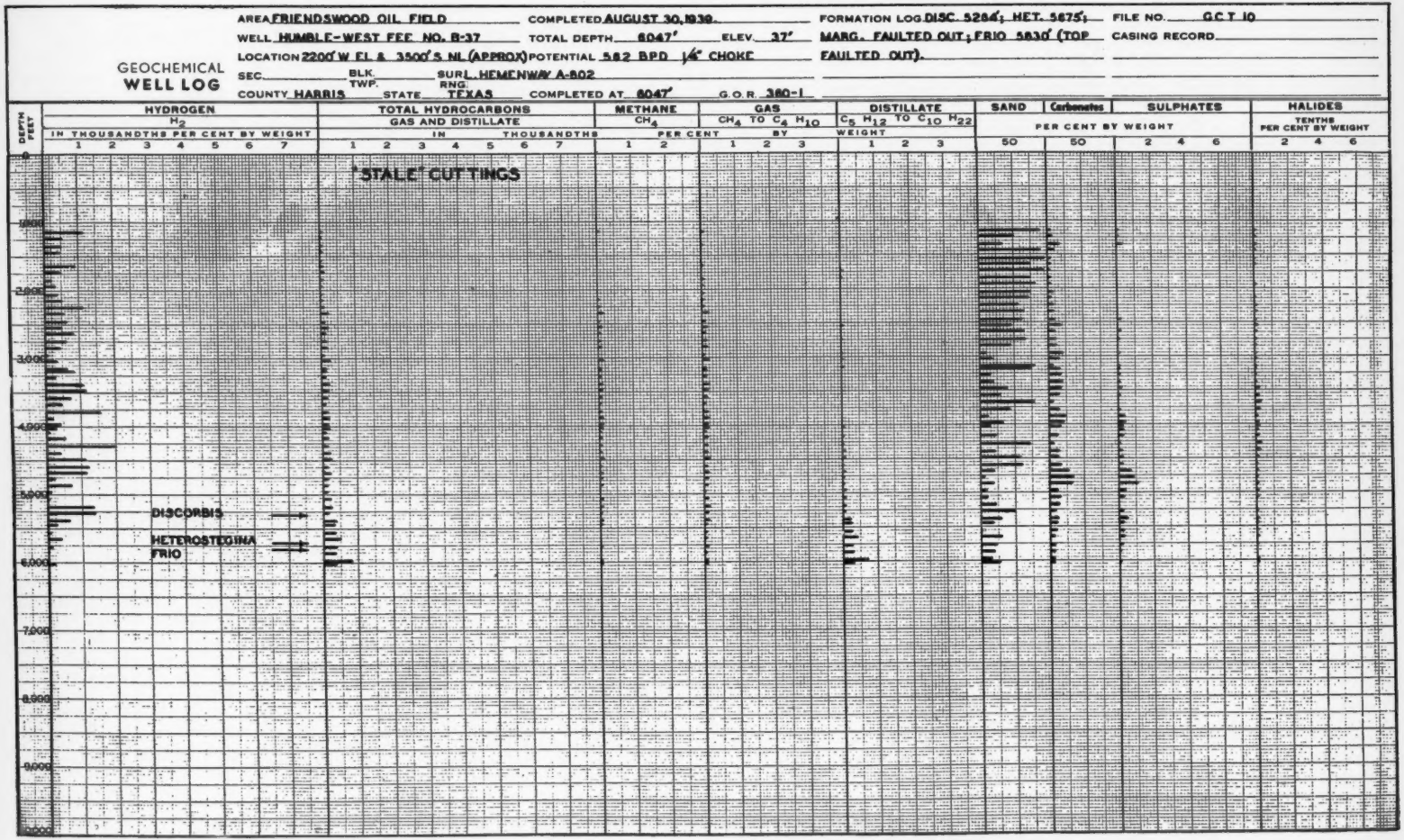


FIG. 11.—Geochemical log, edge producer, Friendswood oil field, Harris County, Texas.

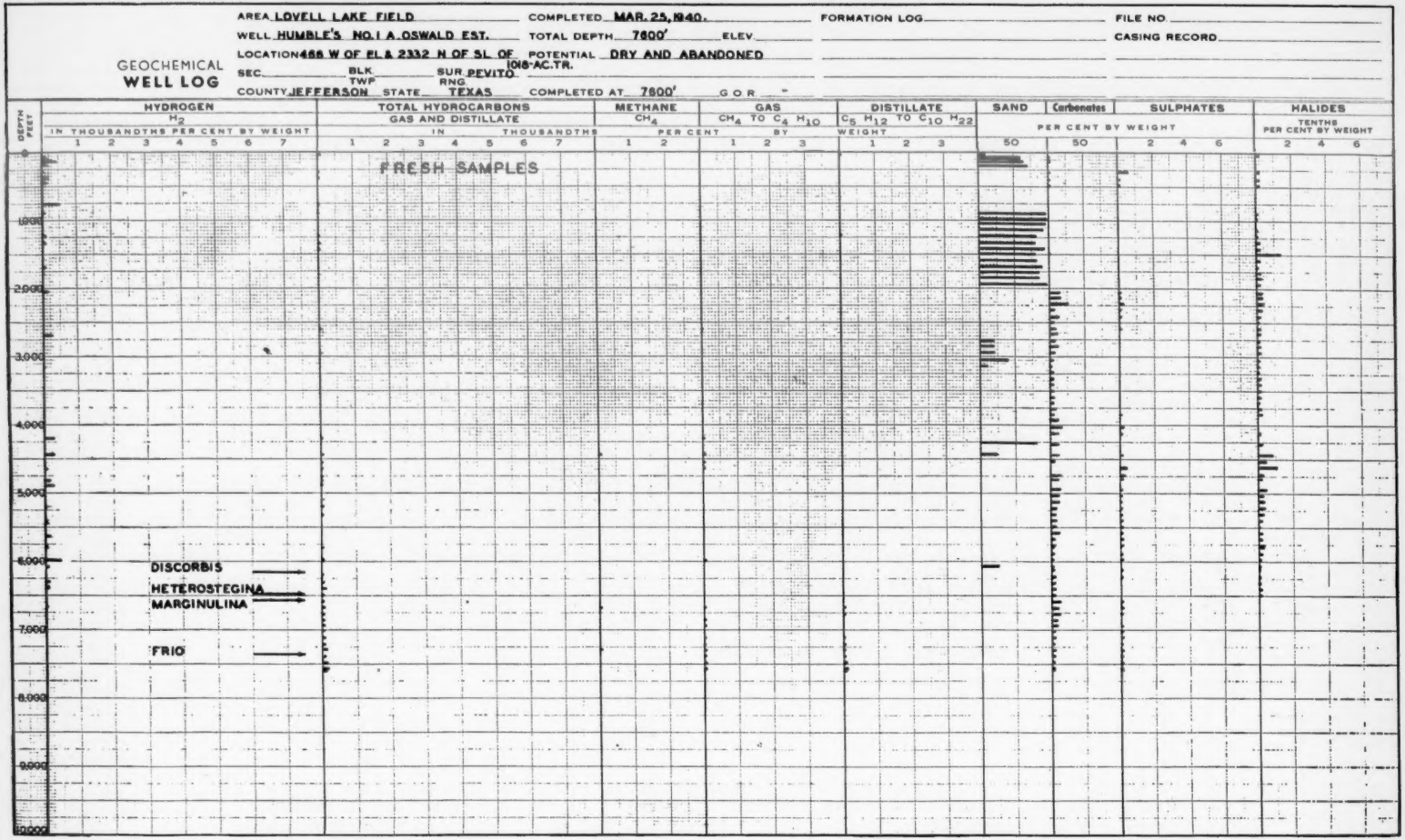


FIG. 12.—Geochemical log, dry hole, about 3,500 feet outside (present) limits of production, Lovell's Lake oil field, Jefferson County, Texas.

FIG. 12.—Geochemical log, dry hole, about 3,500 feet outside (present) limits of production, Lovell's Lake oil field, Jefferson County, Texas.

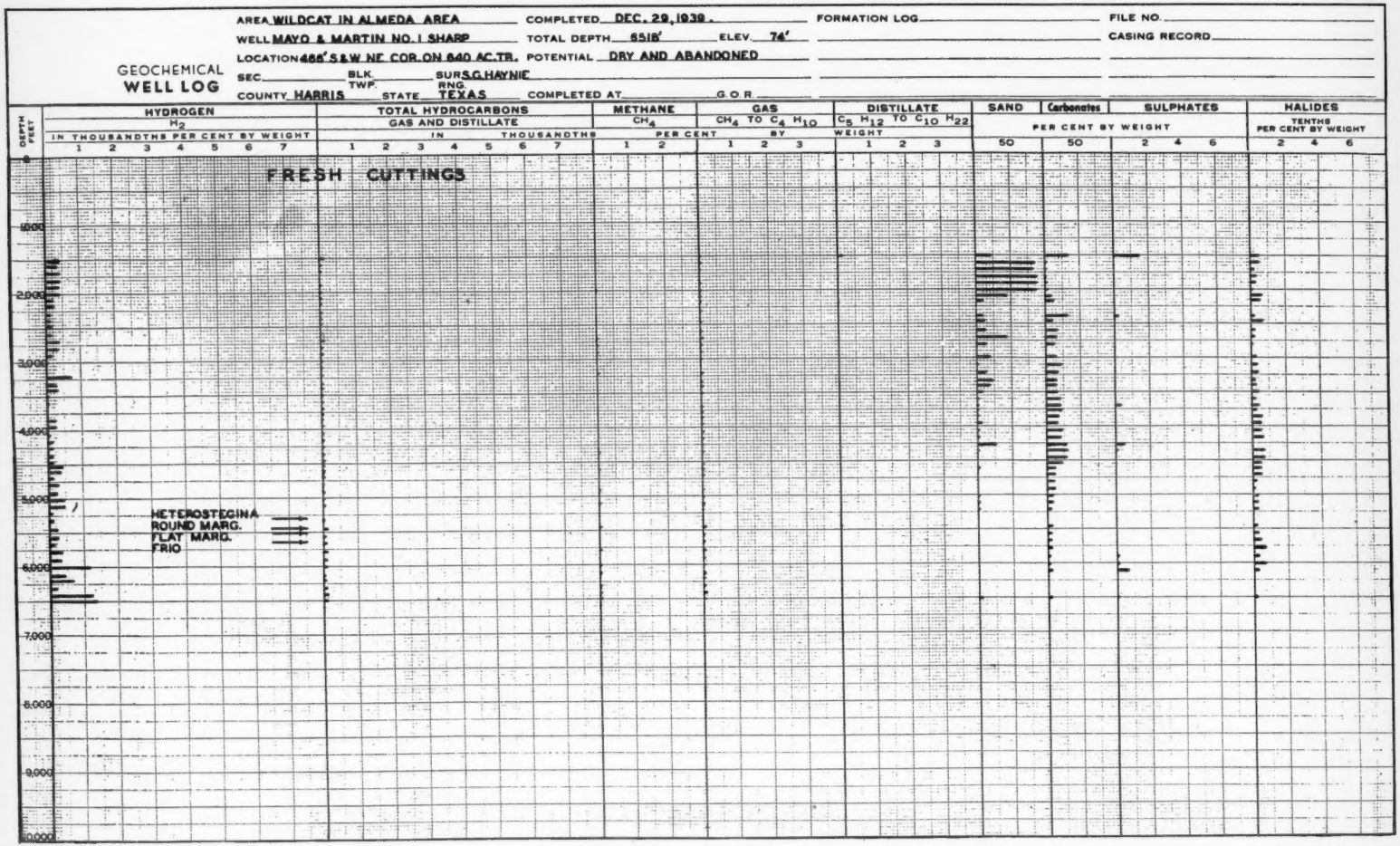


FIG. 13.—Geochemical log, dry hole, no showings reported, Harris County, Texas.

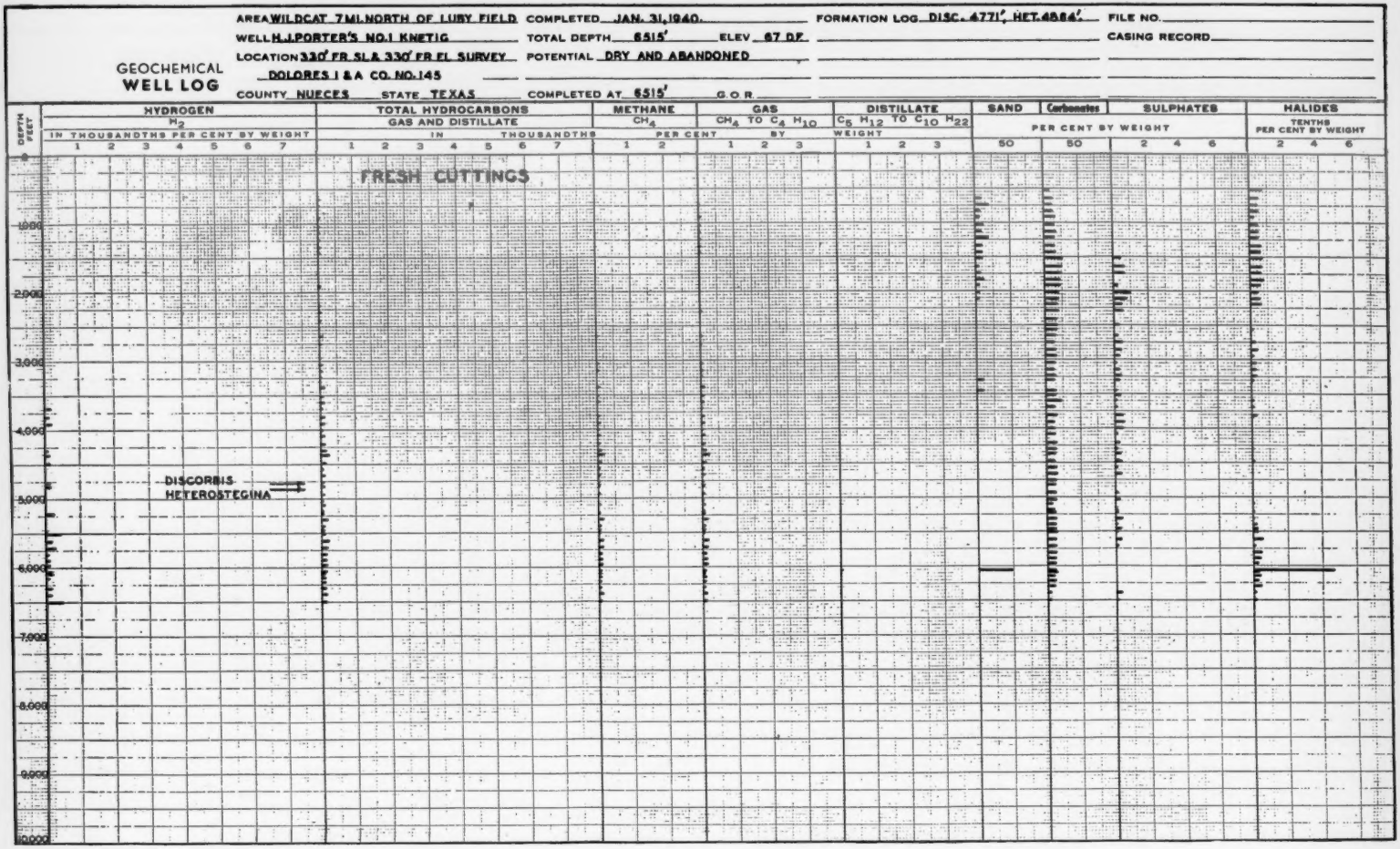


FIG. 14.—Geochemical log, dry hole, no showings reported, Nueces County, Texas.

GENERAL CONSIDERATIONS

Under the subsurface conditions (rock pressure and concentration gradients) existing in a petroleum accumulation, preferential leakage or effusion can be expected along the bedding planes of the more po-

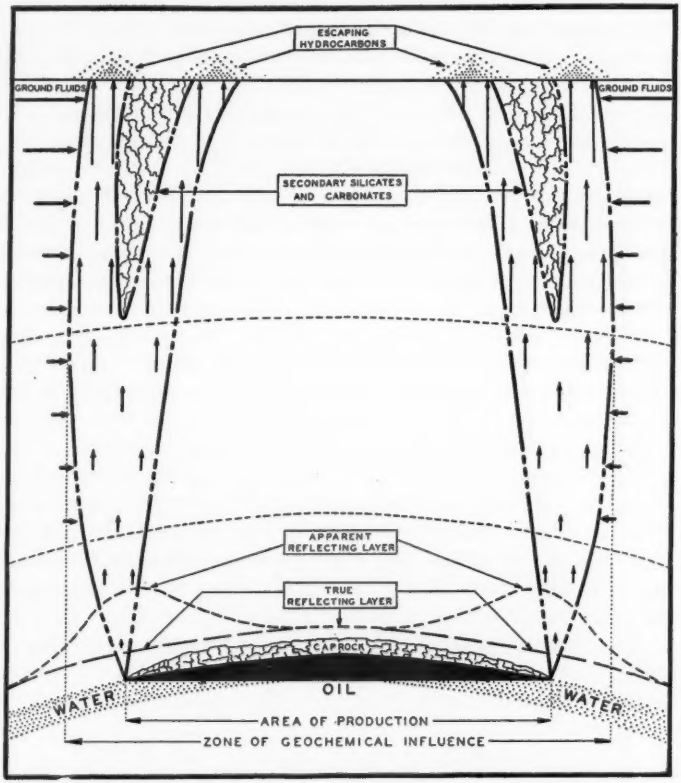


FIG. 15.—Annular geochemical anomaly.

rous strata, and across the bedding planes as well, there assisted by normal jointing and fissuring. As a result, the zone of geochemical influence should extend outside the limits of production, laterally as well as vertically (Fig. 15).

CAP ROCK

We consider that the petroleum accumulation enforces upon its sedimentary environment several geochemical effects. Of these, the primary effect is the cap rock, whether in the form of the thin shell capping the reservoir rock (a condition commonly found), or in the form of the generally denser and more indurated sediments overlying the accumulation. The formation mechanism of this cap rock is not too clear as yet, but it is believed related to two phenomena which can be considered reasonably pertinent. The first of these is the much greater solubility of carbon dioxide in petroleum as compared with water, a relationship which, it has been suggested,[30] results in the conversion of the more soluble bicarbonates to the less soluble carbonates in the presence of petroleum. The second of these is the possible conversion of sulphates to sulphides by the reducing action of either petroleum or petroleum bacteria, a reaction suggested because of the abnormally high concentrations of sulphides commonly observed in the sediments overlying a petroleum accumulation.[31]

Whatever the actual mode of formation, the cap rock appears to originate the annular effusion of hydrocarbons which is observed in the near-surface soil as the halo associated with an underlying deposit of petroleum.

Other significant geochemical phenomena are illustrated in Figure 15. The writer had previously postulated that both hydrocarbons and mineralized ground waters migrated upward from a petroleum deposit across the bedding planes.[32] However, I. J. Fenn[33] has challenged that hypothesis for the migration of ground waters, and has proffered a more plausible hypothesis[34] for the origin of the near-surface inorganic geochemical phenomena, in brief as follows.

Attention has been called, previously, to the evaporative effect of hydrocarbons escaping from a reservoir. Torrey[35] and, even earlier, Mills and Wells[36] had postulated that effect to account for the "dry

[30] Paul Weaver, personal communication.

[31] See appended bibliography, 8, 9, 11, and 12.

[32] E. E. Rosaire, "Shallow Stratigraphic Variations over Gulf Coast Structures," *Geophysics*, Vol. 3, No. 3 (1938), pp. 96–115.

[33] Staff geologist, Subterrex.

[34] I. J. Fenn, "An Hypothesis for the Origin of Certain Geochemical Anomalies Associated with Petroleum Accumulation." Read by title before the Association at Chicago, April 11, 1940.

[35] Paul D. Torrey, "Composition of Oil-Field Waters of the Appalachian Region," *Problems of Petroleum Geology* (Amer. Assoc. Petrol. Geol., 1934), pp. 841–53.

[36] R. van A. Mills and Roger C. Wells, "The Evaporation and Concentration of Waters Associated with Petroleum and Natural Gas," *U. S. Geol. Survey Bull. 693* (1919).

sands" and highly mineralized connate waters observed in the reservoir rocks of Pennsylvania.

Fenn has pointed out that a similar evaporative effect should accompany the migration of hydrocarbons through the sediments overlying a petroleum deposit. Two corollary effects are present, as follows.

As the hydrocarbons migrate to zones of lower pressure, they take on the gaseous phase at some general depth zone (if not already in that phase). Further migration in the same direction results in a continuous increase in volume, so that they would continue to evaporate water. This evaporative action apparently concentrates the normal ground minerals, by removing the water from the normal ground fluids. Most important of all, however, since the volumetric increase per unit depth change is greatest in the surface and near-surface sediments, the evaporation of ground water and the resulting ground-mineral concentration also are at a maximum in the shallowest sedimentary zones.

The second corollary effect is the replacement of the evaporated ground water by normal ground fluids, migrating inward toward the escape paths as a result of osmosis and capillary action.

This inward drift localizes laterally the escape paths of the hydrocarbons, and so opposes and reduces to a minimum the natural diffusion processes which otherwise would result in broad, diffuse, and poorly defined near-surface phenomena. As a result, even deep-seated accumulation is associated with localized near-surface geochemical anomalies, such as the typical hydrocarbon halos, annular seismic and Eltran anomalies, and gravity minima or maxima.

The escape history of the effusing hydrocarbons in the upper sediments should be essentially the same, once the gaseous phase has been assumed. As a result, for hydrocarbons effusing from any source below that general zone at which the gaseous phase is assumed, the geochemical phenomena should be similar, and so would be independent of the depth at which the source is buried.

Prior to assuming the gaseous form, effusion is assumed to take place primarily because of concentration gradients, and secondarily because of pressure gradients.[37]

These near-surface geochemical phenomena result from processes which are very small in magnitude at any given time, but which yield effects which accumulate to appreciable magnitudes in their directed action over geologic time.

In such a concentration of normal ground minerals, precipitation of the least soluble constituents eventually takes place. The general

[37] T. V. Moore, personal communication.

case, as illustrated, is that of the annular anomaly in the near-surface sediments, probably due to the secondary deposition of silicates and carbonates. This annularity has been observed in the Gulf Coast, South Texas, the Permian basin, Illinois, and California, over stratigraphic traps (sand lenses and overlaps), as well as over structural traps, *but only when such traps are reservoirs of petroleum.*

The secondary deposition and cap-rock formation modify the physical properties of the sediments in several ways. Among these (modifications) are local induration and increased seismic speeds, and the anomalous densities, elasticities, and electrical conductivities which also have been observed in the affected sediments. All these effects are localized in significant patterns in the surface and near-surface sediments over and around the petroleum accumulation.

CONCLUSION

The case treatments presented illustrate the scope and the future importance of geochemical prospecting for petroleum. As a result of the past successes of geological and geophysical (structural) prospecting, we now are forced to the consideration of exploration for *petroleum* enclosed within low-relief structures and stratigraphic traps. Under such conditions, the petroleum accumulation itself, through its geochemical manifestations, should prove to be a more readily attainable objective than the trap in which it is enclosed.

In this fundamentally important field of microscopic geochemical prospecting, new problems are encountered, and older problems, such as the depth to the accumulation itself, arise to demand solution.

In our pursuit of geochemical prospecting, we can expect to make progress in the solution of two problems which are at least of theoretical importance. One of these is the history of the accumulation, and the other is the origin of petroleum itself.

In his study of an ore body, the mining geologist finds the geology and geochemistry so closely interwoven as to permit no real separation. One might generalize, and say that the geology of an ore body is of assistance primarily in reconstructing the history of the associated structure, while its geochemistry is of assistance primarily in reconstructing the history of the deposit itself. Actually, no such broad division is possible, and, in practise, the two approaches are blended in the solution of a common problem.

However, we have neglected the geochemistry of a petroleum accumulation, and so are much better informed on sedimentary and structural history than we are on the history of the petroleum accumulation itself. Consequently, we have been able to do no more

than speculate about the relative importance of lateral or vertical migration *versus* origin in place. And as to the petroleum itself, controversy has raged for years as to the greater possibility of several possible origins. At the present time, we probably are in a position to discuss the origin of oil only in qualitative terms.

However, as we investigate the geochemistry of petroleum deposits, we can develop the solution of those problems in a truly scientific manner. First will come the accumulation of data as to relative times of structure formation and petroleum accumulation, largely from geochemical well logging and subsurface petrographic studies. Our objectives will be, first, the recognition of localized sedimentary variations which have a significant geochemical origin, and, second, the reconstruction of their histories.[38]

Research of this sort should make it possible to date the accumulation and perhaps the petroleum itself relative to its sedimentary environment and to the formation of the trap within which it is enclosed.

At that time, and not before, we will be in a position to formulate rational hypotheses as to the history of the accumulation itself. Our formulation of rational hypotheses as to the origin of the petroleum itself will be still farther down the road. Lacking such a fundamental approach, our present state of knowledge permits not much more than speculation as to the history of the accumulation and the origin of petroleum.

Geochemical prospecting requires that the geophysicist and geochemist furnish quantitative data of widely differing kinds, and that the geologist interpret those data properly and without prejudice as to their origins. The data and their interpretation are inseparable, for in geochemical prospecting the three professions have a common meeting ground.

Obviously, the optimum results will follow from the proper interpretation of high-quality data, for the exploration chief of staff can not hope to make bricks without straw. A poor interpretation of good data is always subject to revision, but a brilliant interpretation of low-quality data is a very exceptional and fortunate event which can not be expected in routine operation.

Geochemical prospecting yields data which have permitted the formulation of rational hypotheses and exploration tactics applicable

[38] One such approach of potential interest would be the determination of the apparent radioactive age of the sediments over an oil or gas field as compared with the radioactive age of like and adjacent sediments. Differences might be expected to follow from the secondary accumulation of normal background radioactive minerals through the evaporation-replacement cycle previously described. Similar studies should be made of the petroleum itself.

in stratigraphic prospecting, and these should play as prominent a part as the anticlinal theory and the hypothesis of gravitation separation did in the era of structural prospecting now drawing to a close. Just as geological and geophysical prospecting did in their days, geochemical prospecting is revolutionizing the tactics of exploration for petroleum. Certainly, even in its adolescence, geochemical prospecting has opened new vistas for geological investigation, interpretation, and speculation, and has indicated the inadequate scope of our present geophysical prospecting techniques.

ACKNOWLEDGMENTS

In addition to the personal contributions mentioned in the footnotes, there have been other workers in this field who also have contributed to the developments which have taken place in geochemical prospecting, primarily those individuals and organizations which have been trying and investigating this new field during the formative stage of the past 4 years. In particular, the writer wishes to point out that this discussion has been built on a framework which is largely the result of the experimental contributions of Leo Horvitz[39] and L. W. Blau,[40] and the theoretical contributions of I. J. Fenn.[41]

Personally, the writer wishes to express his indebtedness to A. I. Levorsen who was primarily instrumental in organizing this symposium, and whose paper on stratigraphic prospecting,[42] in 1936, served both as an inspiration and as a challenge to those of us who felt that the last chapter in prospecting yet remained to be written.

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[39] Chief geochemist, Subterrex, Houston, Texas.

[40] Chief, geophysics research, Humble Oil and Refining Company, Houston, Texas.

[41] Staff geologist, Subterrex, Houston, Texas.

[42] A. I. Levorsen, "Stratigraphic Versus Structural Accumulation," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 20, No. 5 (May, 1936), pp. 521–30.

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DISCUSSION OF GEOCHEMICAL EXPLORATION (SOIL ANALYSIS)[1]

E. E. ROSAIRE, EUGENE McDERMOTT, R. H. FASH ET AL.

QUESTION: What are the effects of seasonal variations on soil analyses?

ROSAIRE: When sampling above the water table, the wet season generally is characterized by soil concentrations of unoxidized hydrocarbons which are higher than the soil concentrations of oxidized hydrocarbons. In the dry season, the reverse is generally true, that is, the soil concentrations of the oxidized hydrocarbons approach or are higher than the soil concentrations of unoxidized constituents.

In general, non-significant variations are minimized by the use of greater sampling depths. Other things being equal, the following general depth zones are important. Below plow depth, cultural variations should disappear; below root depth, vegetation differences are minimized; below the frost line, temperature differences should disappear; and below the water table, oxidation and evaporation phenomena should be at a minimum. These considerations have led us to the practise of sampling at uniform depths, for these general depth zones tend to follow the topography.

McDERMOTT: The seasonal variation, I think, will depend on what you are measuring. I say, naturally, if you are measuring gases which are leaking through the earth and being absorbed they are, of course, at the same time being evaporated. Depending on the dynamics of that process, it may be that you will observe seasonal changes. The heavier constituent which we have measured and which takes years to form is probably subjected to some seasonal changes, but in view of the fact that they are formed over a large number of seasons the seasonal effect is averaged out, so far as we can detect. We have made measurements on samples taken in the summer and winter, and I think it is reasonable to expect that any constituent which takes, let's say, 10 years to form shouldn't change very appreciably from season to season. We have measured samples taken in winter and summer and have not noted any great difference. Measurements were not for gases which may show seasonal change.

QUESTION: Is it not necessary to take samples below all younger mantling deposits, such as loess, glacial drift, terrace gravels, alluvial fills, etc., in order to get reliable results?

ROSAIRE: The specific answer to this question is that, in the type of deposits mentioned, usable and significant data have been secured by sampling in the near-surface soils and, under favorable conditions, even in the top soils.

However, the best sampling depths are those which reach below the water table and into bed rock. Sampling at shallower depths raises the question of the minimum time required to establish these geochemical phenomena, that is, a week, a month, a year, up to geologic time.

[1] Note.—The questions and answers of both symposia, in so far as they pertain to geochemical exploration (soil analysis) are brought together here. Some of these questions were answered orally at the time of the evening symposium while others were submitted to the speakers later and all have been edited by the participants in the discussion. The contribution to the symposium by Eugene McDermott was published in the *Bulletin*, Vol. 24, No. 5 (May, 1940), pp. 859–81, to which the reader is referred.—A. I. L.

We have contemplated the establishment of central stations, where a hydrocarbon-free medium, similar to soil, is exposed to known seepage, so that the hydrocarbon content can be determined from time to time. We have not proceeded with that attack because we have observed natural phenomena which serve the same purpose, as follows.

During the wet season, much of the Gulf Coast soil is well saturated with water, while the soil in the same area, in the dry season, is thoroughly dry down to 10 or 15 feet, and is extensively sun cracked. In the dry season, we have found that soil samples collected at a given spot at a depth of about 5 feet display relatively low soil-hydrocarbon concentrations. However, in the wet season, samples collected at the same spot and at the same depth, display significantly higher hydrocarbon concentrations. This phenomenon has been observed in widely separated areas. Having been observed over several years, this seasonal variation in hydrocarbon content is so definitely established that we specify greater sampling depths in the dry season than in the wet season.

We interpret these observations to mean that the hydrocarbons effuse through the soil at essentially constant rates, and that, as a result, these upper soil concentrations are substantially established in a minimum time of one (favorable) season.

Our experience shows that allowance must be made for the cultural modification of the properties of the upper sediments. Thus, we prefer to locate sample points about 50 feet away from a road bed, for samples collected in the bar pit usually show smaller concentrations than samples collected across the fence well into the near-by field. That difference is considered to follow from the compaction of the soil which accompanies road making and the pounding of resulting traffic. Similarly, it is inadvisable to collect samples in "made" canal levees where the overlying sediments no longer display physical properties similar to those displayed by the adjacent and undisturbed geological equivalents. In other words, variations due to local culture appear to be of more importance than the geological age of the mantling deposits.

E. B. NOBLE: Assuming that a geochemical survey is made over a large area and that all samples are taken at a uniform depth of 10 feet; also assuming that there is a reasonable amount of dip and that some of the samples consist of clay or silt and others of sand; then under these conditions would it not be possible that the percentage of hydrocarbons in the individual samples would be more closely related to the nature of the sample material than to its position over the oil body?

ROSAIRE: For some time we have been on the watch for a basic relationship between the mechanical and physical properties of the samples and their concentrations of significant hydrocarbons. It is probable that such a factor exists, as has been suggested by some of the data at hand, though it is not, as yet, outstandingly obvious, nor is it of fundamental importance *at the present stage* of geochemical prospecting.

Such correction factors are comparable to refinements in "weathering" calculations in reflection prospecting. The need for such refinements became evident as we were forced progressively to consideration of anomalies of smaller magnitude than those which were obvious in the early reflection prospecting. In 1930–1931, in order to recognize the reflection dip closure which was confirmed by the discovery well at the Iowa oil field, there was no need to introduce weathering corrections, or, for that matter, even "time breaks."

Eventually, we will be forced to give consideration to geochemical anomalies where the magnitude of the correction required is equal to or greater than the magnitude of the anomaly itself. At present, that is not necessary, for many geochemical anomalies remain to be discovered which are quite obvious without the use of refined correction factors.

QUESTION: What concentration of hydrocarbon gases (part per million) is considered to be significantly indicative of petroleum deposits?

ROSAIRE: I don't know that such yardsticks are available. We started our early work relying entirely on the very sharply defined ethane fraction. As we have progressed and built up experience, we have found it permissible to broaden that fraction more and more. Our yardsticks are becoming better established, but as yet we place most reliance on the relative contrast displayed by the anomaly in terms of the background values.

To illustrate the difficulty of establishing such yardsticks in geochemical prospecting, I wish to call attention to the elastic nature of the yardsticks used in structural prospecting.

There we speak of A, B, C, D, etc. classes of prospects, based on the amount of closure observed. Practically, we never have "A" structures available for consideration, for those are all leased and/or producing. At present, the Eola oil field is rated an "A" class reflection structure for the Sparta Wilcox trend in the Gulf Coast. However, at the time that it was first recognized by reflections (about 1935), it was rated a "C" or "D" class prospect because of its low relief (as compared with Hastings), and was not generally regarded as of material interest.

In other words, common practise is to use a rubber yardstick in structural prospecting. That practise is a natural consequence of the progressive elimination of the structures of higher relief, for those of lesser relief become more important as prospecting continues.

If several decades of structural prospecting have not brought forth a "standard meter," then it can hardly be advisable to require that such be imposed now, if ever, upon this relatively youthful phase of geochemical prospecting.

F. M. VAN TUYL: Is it necessary to assume that all the hydrocarbons in the soil and in the underlying strata have escaped from an oil or gas pool? They may be generated in relatively shallow deposits under favorable conditions.

MCDERMOTT: I think, definitely, you can't say that all the hydrocarbons in the soil come from oil and gas accumulations, for the very simple fact that we find such hydrocarbon concentrations everywhere, whether there is oil or not. I may say that we find high concentrations, higher than those background values, associated with the oil accumulation, and on a purely empirical basis we have been led to believe, by making a sufficient number of measurements, that generally speaking we will find such high concentrations connected with the oil accumulation. Some accumulations will leak very readily; others will not leak in sufficient quantity to permit an interpretation of the data.

As to why some of them show a great deal of leakage and others very little, I don't think there are sufficient facts at hand at the moment to arrive at a definite conclusion. The surprising thing is that the Cedar Lake pool,

over which we collected data, is not a high-pressure pool, and is probably the outstanding survey we have made. One would expect, offhand, that the higher the pressure the greater the leakage and, consequently, the higher the concentration pattern near the surface.

I can only point to that one case, where the concentration pattern near the surface was excellent, and still it is a very low-pressure pool, so low in pressure, in fact, that gas from the Yates sand above is used to flow the wells. We must bear in mind that, even in that case, it may be the pool has higher pressure than we think and perhaps, as a result of lower permeability—it is a limestone pool—there is not enough pressure to flow the oil under flowing conditions.

QUESTION: Why would you not get leakage at updip edge of a stratigraphic trap, as well as from the downdip edge?

MCDERMOTT: That takes you into the theoretical considerations, which I didn't want to go into to-night because, if you do, you either have to go into them exhaustively or not at all.

I might say, however, that in the field of theory I have made a few assumptions which are, of course, predicated upon observations. One is that the oil accumulation results from the polymerization of gases leaking through the earth. The other is that the type of accumulation is a function, I think, almost entirely of characteristics of cap rock, especially the permeability of the cap rock. If those assumptions are correct, the leakage must occur along the free edge around the accumulation, based on the fact that the accumulation is growing. In the case of the stratigraphic trap or a trap against a fault of low permeability, the accumulation can't grow in that direction, and you won't have leakage in that direction.

The only justification for these theoretical assumptions is the fact that the deductions which logically follow from those assumptions do, so far as I know, fit all the observational data that I know of.

ROSAIRE: I would like to point out that in at least two cases where we have worked across a stratigraphic trap, we have gotten definite leakage on the up dip end of the trap. (See Fig. 2, p. 1404.)

QUESTION: Will not mere showings (non-commercial) of oil and gas at a shallow depth simulate surface seepages of a commercial deposit at much greater depth?

ROSAIRE: In geochemical well logging, the hydrocarbon concentration depth patterns in the immediately (vertically) adjacent sediments usually are noticeably different for sands with "non-commercial" accumulation (shows) than for sands with "commercial" accumulation.[2]

We recently observed a (Gulf Coast) near-surface hydrocarbon halo which was outstanding in our experience. In this area the background concentrations (of ethane, propane, and butane), for a mile or so outside the halo, were less than 50 parts per billion, while the halo (of similar hydrocarbons) was drawn so as to include concentrations of 500 to 1,000 parts per billion. A test well,

[2] This experimentally observed difference, between "non-commercial" shows and "commercial" accumulation, was of material assistance in formulating our present "dynamic" conception of the petroleum accumulation as contrasted with the former "static" conception.

drilled to 3,500 feet within this geochemical anomaly, reported several non-commercial shows, none of which, on the geochemical well log, displayed significant concentration depth patterns. Quite reasonable subsurface estimates place, some 3,500 to 4,000 feet deeper, a geological formation from which, 25 miles updip, and about 40 miles away, three fields, of reasonable areal extents, have produced more than 100 million barrels of oil. Further, some 300 miles away, along dip, the stratigraphic equivalent of that same formation has produced, along a definite structural trend, more than 1 billion barrels of oil.

In view of these considerations, which of the following hypotheses is the more reasonable?

1. This outstanding hydrocarbon anomaly originated from the non-commercial shows at 3,500 feet; or

2. This outstanding hydrocarbon anomaly *and* the non-commercial shows at 3,500 feet originated from petroleum accumulation, very probably of commercial importance, in the deeper, as yet untested, formation which is known to have major potentialities for production.

H. K. ARMSTRONG: What evidence do you have that the surface data are related to deep commercial accumulations rather than to an overlying gas or non-commercial accumulation?

ROSAIRE: The evidence at hand is empirical, as follows.

Two wildcat tests, scheduled for abandonment on reaching contract depths, have been carried deeper to production on the basis of anomalously high concentrations of hydrocarbons (among which were ethane, propane, and butane) observed in the lower sections of their geochemical well logs. In other cases of geochemical well logging, confirmation has followed the predictions (of the presence or the absence of accumulation) for depths not then reached by the drill, based on the concentrations of those same hydrocarbons in the cuttings.

In South Texas, soil analyses indicated the presence of an ethane halo around the established limits of production at a depth of 1,500 feet in a sand lens. In the same survey, a similar ethane halo was observed, about a mile away, along strike. There, subsequent drilling developed production of the same type as that previously established.

At the Eureka oil field in the Gulf Coast, and at the Ramsey oil field in Oklahoma, the associated halos of significant soil hydrocarbons have been shown, by subsequent drilling, to be closely related to the limits of production. Widespread evidence of a similar kind is accumulating in the Gulf Coast and California.

Certainly in those cases, it is reasonable to assume that the significant soil hydrocarbons had their origin in the petroleum accumulation itself.

Admittedly, not all such soil hydrocarbon concentrations are related to petroleum accumulation of economic importance. Not all anomalous surface dips are significant, for some are the result of cross bedding.

On the other hand, "dry" holes have been and probably will be drilled on geochemical anomalies which must still be considered significant even in the face of such adverse evidence, for associated petroleum accumulation of economic importance still could exist at depths not reached by the drill. The ethane halo at the Eureka oil field has stood the test of subsequent drilling,

yet had those data been placed on record 10 years ago, the geochemical anomaly would have been "disproved" by "dry" holes of the shallower depths characteristic of that time.

As a further point, our "commercial" and "non-commercial" yardsticks are subject to modification as progress takes place in well-completion practise. In several fields, "commercial" production has been established under conditions which would have been considered "non-commercial" 10 years ago.

QUESTION: There are certain areas of universally oil- and gas-bearing beds whose porosity and permeability is so low that, except locally, only showings result. May not such a broad area be indicated as generally productive by soil analysis whereas actually only small locally porous lenses would produce commercially?

ROSAIRE: The terminology of the question is not exact. One can hardly say that an area would be shown "generally productive by soil analysis," and yet have only small local lenses commercially productive. It would be better to say that a soil-analysis survey might show general soil-hydrocarbon concentrations large enough in magnitude to be considered as of possible significance, and yet which would result in production which would be disappointingly low.

The extreme case would be even worse. A soil-analysis survey might be made of an area where oil shales were covered only by a thin veneer of soil, and result in amazingly high soil concentrations of hydrocarbons. Asphalt and oil seeps have been reported which unquestionably represent migration along permeable zones to their outcrop, that is, these are cases of visible seeps of oil and gas which are not related to (underlying) commercially utilizable accumulation. I consider it quite possible that, under such circumstances, erroneous conclusions might be drawn which would lead to the drilling of dry holes.

No prospecting method is infallible, and the best prospecting method is subject to misuse. Of a group of men who are similarly equipped, some will be outstanding, others mediocre, and still others will prove to be miserable failures. A degree in geology does not insure eminence in this Association. Hiring a reflection-seismograph crew does not insure discovery of an oil field. The time, the place, and the individual will be as important as, perhaps more so than, the choice of prospecting method.

The principles of prospecting hold for geochemical prospecting just as they have held for all previous prospecting techniques. In its (eventual) turn, geochemical prospecting will display the diminishing returns now characterizing the older and established exploration techniques.

In the proper hands, and almost overnight, the refraction seismograph was metamorphosed (from a technique which had displayed only indifferent success for more than 2 years when tried in Mexico, Oklahoma, the Balcones fault line and the Gulf Coast) into a technique which operated with brilliant success, and which, 3 years later, established the highest rate of finding to date.

Admittedly not infallible, and certainly subject to misuse, the fundamentally important consideration is that microscopic geochemical prospecting is intimately related to megascopic geochemical prospecting, a rational and direct prospecting technique which was responsible for the discovery of more petroleum in more areas than any other exploration technique yet de-

veloped. The problem before us is not the recognition of conditions under which microscopic geochemical prospecting is certain to fail, or may fail, but the recognition of those conditions under which it can be used to advantage in exploration for petroleum. At present, we are familiar with too many methods which, even under the most favorable conditions, involve undue hazard in prospecting. As prospectors for petroleum, we should concern ourselves with next year's batting average, for only the production department is interested in the batting averages already on the record books.

It has been said that "To the private, war is a trade, to the officer, a science, and to the general, an art." Similar viewpoints will hold in prospecting for petroleum. The laboratory analyst determines the hydrocarbon concentrations in samples of soil or well cuttings, and he, usually, will be the least likely to draw the proper conclusions from such data. I placed the responsibility for the accuracy of the data upon the geochemist and the geophysicist, and the responsibility for the validity of the interpretation upon the geologist, who, also, is responsible for the choice of the area explored.

QUESTION: If oil and gas migrate as postulated, how did it ever accumulate in a trap?

MCDERMOTT: If you find a high concentration of hydrocarbon material, it must certainly have come from some place. It is much easier for me to imagine gases doing the moving, rather than liquids. The reason for accumulation is explained in my paper entitled "Concentrations of Hydrocarbons in the Earth," *Geophysics* (July, 1939); also in my paper, "Geochemical Exploration," *et cetera*, *A.A.P.G. Bulletin* (May, 1940).

F. F. CAMPBELL: How can unsaturated hydrocarbons migrate any great distance vertically without becoming saturated?

MCDERMOTT: I really don't know. Neither am I sure that unsaturated hydrocarbons migrate any great distance in any great quantity. However, I don't see how you can preclude the possibility of small quantities, at least, moving considerable distances. They are going to become saturated, for instance, only when they are brought in contact with a catalytic agent, or something to saturate them. It is quite possible they can move through the voids in the earth without so coming in contact and, therefore, can migrate long distances without becoming saturated. It is not absolutely essential to the theory that unsaturates be present. It is easier to explain the phenomena if they are.

Chairman LEVORSEN: We have several questions along this general line: "What data are available as to concentrations along the axes of sharply inflected folds and along surface faults?"

MCDERMOTT: From theoretical considerations maximum leakage should occur at the edges of gently folded structures. Likewise, based on theoretical considerations, the maximum leakage should occur over the top of accumulations in steeply folded structures. This is simply due to the fact that in the case of steeply folded structures, the cap rock has been cracked, thus permitting the accumulation to leak over the top. That, of course, would be classified as a dying oil accumulation. I think all of the accumulations, where leakage occurs around the edges, must be classified as growing accumulations.

So far, in view of the fact that practically all of the work has been done

in areas of gentle folding, we do not have much data in support of the high concentration pattern that you might expect over a steeply folded accumulation. We obtained some data at Big Lake, where we did get such a high concentration pattern over the accumulation, and the fold is fairly steep there. However, I don't feel that that is very conclusive, because there is a possibility of contamination there, inasmuch as that is a very old field. The wells were undoubtedly not completed as well as they are nowadays, and the high concentration pattern there might be due to leakage around the casings.

We have, however, one case, which unfortunately I can't disclose, where we have obtained a high concentration pattern—a very good one—with the mineral pattern agreeing over a highly folded structure.

QUESTION: If you are going to have your fissures present, why do you have the leakage on top of the structure, and not on the side?

MCDERMOTT: As I mentioned before, it is an observational fact that we don't have leakage there in the case of gentle folding. Therefore, there must be some reason why there is less leakage over the top than there is over the edge. Of course, I have made the assumption that it is because of the fact that the cap rock over the top, for some reason or other, is made less permeable. I think it is due to a "clogging" effect when the heavier hydrocarbons are formed.

As I say, if you grant the assumption that the oil field results from the polymerization of gases leaking through the earth; that it started that way and continues as a result of the gases coming from below and dissolving in the oil and polymerizing to form more oil; if that is the case, it follows as a necessary consequence of that assumption that you certainly can't have a high over the oil field. If the oil field is going to form and grow, less can leak out than leaks in. If you grant that assumption—mind you, it is just theoretical—then you can't have a high over the top of an accumulation. That is just part of the theoretical construction that is evolved from the data of geochemistry.

W. P. HAYNES: Why doesn't the gas escape from the fissures along the anticlinal axes instead of on the flanks or edge of the oil body as drawn by Mr. McDermott?

Rosaire also used the halo as the principal type of escape. This would appear to hold for a salt dome with impervious cap, but otherwise I see no reason why the top of the fold or dome should not leak more readily than the flanks.

MCDERMOTT: The fact that the leakage occurs around the edge instead of over the top is simply an observational fact. We have observed in many cases that it is the type of leakage we get (in areas of gentle folding). All the rest is just a matter of trying to explain why you get that type of concentration pattern. I think it is very important that we be careful to separate out observational data from speculation or theoretical conceptions. The occurrence of that type of concentration pattern is simply based on observational data. In areas of steep folding evidence suggests that the leakage is greatest over the top of the accumulation.

J. L. ADLER: Since pressure at any depth is necessarily equal in all directions, why should horizontal cracks be closed any more readily than vertical

cracks? By far the greater number of cleavages in a drill core are parallel to the bedding, not vertical.

McDERMOTT: Of course, when you say "pressure," you are probably referring to hydrostatic pressure and not rock pressure. Obviously, the rock pressure is not transmitted equally in all directions. That is why I think, due to overburden, the horizontal fissures in the rocks will be closed more readily than the vertical fissures.

As far as bedding planes are concerned, of course they show up horizontally.

I don't think any measurements have been made to determine the existence of small fissures, either vertical or horizontal. I know that we have made measurements on shale cores and find that, for instance, the effect of permeability will range from practically nothing to, in the case where we have been measuring permeabilities of 11 millidarcys which, you remember, is twice the permeability of the Bradford sand—that permeability is not the uniform type of permeability you find in the sand, but is very definitely localized in fissures. Those fissures were not visible; they were microscopic ones. Evidence is not conclusive as the process of coring may have caused fractures.

WILLIAM L. RUSSELL: If oil and gas in a porous formation did not migrate chiefly laterally, they would not accumulate in anticlines and stratigraphic traps. If the chief migration is lateral, why are the surface evidences not found chiefly at the outcrops of porous formations, as in the case of many oil and gas seeps? Also why can not the concentric occurrences around producing anticlines be explained as marking the outcrops of porous formations which would normally surround the dome?

Furthermore, many oil pools, especially those on stratigraphic traps, are overlain by water horizons which have a regional dip across the pools. If oil or gas is escaping from the pool, on reaching the water zone it should migrate up the dip instead of continuing vertically across the water-bearing bed. In this case the surface accumulation of hydrocarbons should also be found at the outcrop of the porous beds.

Furthermore, if hydrocarbons can migrate so readily across bedding planes, how can the greatly varying hydrostatic pressure or head of various beds be explained? In some cases the rock pressure of oil and gas pools is less than the head of overlying water zones, and in such cases upward movements of gas seem impossible.

ROSAIRE: I am not prepared to accept this rather categorical premise that petroleum accumulation depends chiefly on lateral migration. I am willing to admit that lateral leakage may take place to some extent along permeable beds, and there is no reason why such leakages should not be observed at outcrops under the conditions described.

We expect that in some cases we will observe patterns of the soil hydrocarbons which are of no significance with respect to the possibility of underlying petroleum accumulation, but which, rather, will be closely related to the surface geology. The recognition of such non-significant patterns is an interpretation problem for which the geologist should be well qualified.

I offered a hypothesis for the halo pattern which seemed most reasonable to me on the basis of the evidence at hand. I admit the possibility that a halo pattern might result under the conditions described by Mr. Russell, but also

I have observed hydrocarbon halos under conditions which preclude this possibility, that is, in the case of a sand lens.

I confess my inability to explain away such theoretical objections as those raised in the question. Once again, I respectfully call attention to our reliance on experimental data, and point out that, having progressed to the point where we are now in position to classify the observed data, we are now cautiously formulating hypotheses which will aid in the organization of these data and in the direction of further effort.

In 1930 and 1931, I encountered similar theoretical objections to reflection prospecting, at a time when we not only had a wealth of reflection records at hand, but also had had reflection predictions confirmed by subsequent drilling.

To-day, we have experimentally established certain previously unrecognized phenomena, and have utilized these phenomena in prospecting with a certain measure of spectacular success which, admittedly, has been interlarded with a certain number of failures.

Our successes indicate the potential importance of geochemical prospecting, while the autopsies which we hold over our failures may indicate the limiting conditions for the use of this new field of endeavor.

The theoretical objections raised in this question will be better applied with a view to improving our working hypotheses than as they are now, in questioning the validity of experimentally established phenomena.

Certainly, there is no unanimity of opinion as to the origin of petroleum, yet I know of no geologist in this field who foregoes the use of an automobile in favor of roller skates or a bicycle because of his concern over possible illegitimacy in the pedigree of the gasoline sold at the corner filling station.

QUESTION: Your first slide assumes upward migration! How can you prove this?

ROSAIRE: A hypothesis is exactly that because it is made up of assumptions based on experimental evidence. Once the assumptions are "proved," progress has been made in the establishment of a new principle.

I proffered a working hypothesis, involving assumptions, which, as such, remain to be "proved." With regard to the proof required, I suggest that the questioner point out his objections to vertical leakage, rather than ask, in a "shot-gun" fashion, for proof.

To me, the evidence which I presented was adequate for the postulation of a working hypothesis, which, obviously, does not indicate that I consider "proof" established.

QUESTION: Could it not be downward? Thus oil could be forming in surface soil by catalytic action or photosynthesis and could then migrate downward into your ideal trap.

QUESTION: How do you know oil does not originate at surface and then migrate downward? Photosynthesis would then help in origin of oil.

MCDERMOTT: Do not know but do not believe so. More reasonable to assume upward migration of gases than downward migration of liquids.

ROSAIRE: This hypothesis of petroleum formation in the surface soil and its downward migration into the deposit (inferred or postulated in these questions) not only requires migration against the concentration and pressure

gradients which exist between the petroleum accumulation and its sedimentary environment, but also requires the formation of hydrocarbons in the near-surface zone of oxidation. This hypothesis also would require a new type of valve to prevent the oil, once in the tanks, from flowing back into a newly tapped reservoir, thus raising production problems which, fortunately, do not generally exist at present.

Chairman LEVORSEN: We have with us this evening in the audience, Mr. R. H. Fash, of Fort Worth, who is also a student and practitioner of one type of geochemical exploration, and he has agreed to tell us some of his ideas about it. I think it will be of interest to you, because he has a different approach to the problem than the previous speakers.

FASH: Mr. Chairman, Ladies, and Gentlemen: In the first place, I want to say that probably not over 2 years ago I didn't believe in soil analyses. Through an accident we developed the method of analyzing soils to determine oil. We were trying to determine whether we were going through an oil-producing zone in a drilling well, and we got such remarkable results that we tried it on soil analyses. Then we got results, and I had to back-water and try to explain why we got them. In other words, I was a skeptic, and I had to convince myself. I will not tell you anything about our method. I am not going into any details in regard to it, other than to say that it is entirely different from anything that has been presented here tonight.

However, in order to explain the results we got, knowing my own skepticism and knowing the skepticism of the geologists with whom I had talked, I tried to formulate the theory of the mechanism of the migration of the gas occurring in the form of minute bubbles, and in order to satisfy myself along the lines of physical-chemical principles, with which I was familiar, I developed the idea that I will give you now [Mr. Fash read his prepared article, which follows].

A THEORETICAL CONSIDERATION OF THE BASIS FOR THE USE OF SOIL ANALYSES IN LOCATING OIL POOLS

In all methods of analyzing soils for the purpose of locating oil pools, the escape of gas from the pool is postulated, which escaping gas ascends to the surface of the ground and its presence is determined by analyzing the soil near the surface. No explanation has been advanced as to the mechanism of the migration of the gas from the oil pool through the caprock and thousands of feet of overlying sediments to the surface of the ground. From the wording of the literature, the inference can be drawn that the gas is considered as migrating in the form of minute bubbles. If this were true, then the question arises, will not bedding and joint planes, steeply dipping strata, and water deflect the migration of the gas so that the soil near the surface of the ground directly above the oil pool will not contain the maximum amount of gas which had migrated from the oil pool? This question has been one of the major factors which has led many to question the practicability of the use of soil analyses in locating oil pools. The following explanation of the mechanism of the migration of the gas from the oil pool to the surface of the ground answers this question and shows that the soil at the surface of the ground above an oil pool will contain gas which originated in the oil pool, regardless of bedding and joint planes, steeply dipping strata, and water.

The rise of a liquid in a capillary tube is a well known phenomenon. Gases and liquids are adsorbed on surfaces. These two facts afford the basis of an explanation of the migration of the gas from an oil pool through thousands of feet of overlying sediments so that the gas arrives at the surface of the ground above the oil pool regardless of bedding and joint planes, steeply dipping strata, and water. Since liquids whose specific gravity, viscosity, and surface tension are much greater than that of gases rise in capillary tubes against the force of gravity, the movement of gas along the film of adsorbed gas on the surfaces of sedimentary particles does not seem unreasonable. Thus the rise of gas from an oil pool to the surface of the ground can be considered as proceeding along the film of adsorbed gas on the sedimentary particles and not in the free space between the particles, whereby bedding and joint planes and steeply dipping strata do not deflect the migration of the gas. There is lateral migration of the gas, but the major effect of the movement is vertical from the pool.

Water strata do not interfere with this vertical film migration of the gas for the following reason. Water wets the sedimentary particles and these particles thus wetted have an adsorbed layer of water which does not flow when the free water moves in the capillary spaces between the sedimentary particles. The adsorbed gas film on the sedimentary particles underlying a water stratum comes into contact with this adsorbed water layer, resulting in some of the gas dissolving in the adsorbed water layer. The gas thus dissolved in the adsorbed water layer permeates the layer causing the water layer to become saturated finally with the gas. At the upper part of the water stratum some of the gas dissolved in the adsorbed water layer leaves the water layer to enter the adjoining adsorbed gas film. The concentration of solutes at the interface of phases is a well recognized phenomenon. Thus the gas required to saturate the water layer is assumed to be only that required by the water layer and not the amount of gas necessary to saturate the water lying in the free space between the sedimentary particles.

The phenomenon of catalytic action is attributed to a surface effect of the catalytic agent. The practically infinite surface with which the gas from the underground reservoir is in contact while passing from the reservoir to the surface of the ground in the adsorbed gaseous film plus geologic time is assumed to result in the catalytic transformation of some of this adsorbed gas. The effectiveness of this transformation is not only dependent on the surface of the sedimentary particles, but also on the materials composing the strata. Thus variations in the amount of catalytically transformed gas will occur. In some methods of analysis, the adsorbed gas on the soil particles is removed and the composition of the gas is determined. In one method of soil analysis, the adsorbed gas on the soil particles is not analyzed, but a material formed by catalytic action from the adsorbed gas is determined; the results being expressed as parts per million of oil.

The amount of gas adsorbed on soil particles is a function of temperature, pressure, surface conditions of the particles, and the nature of the gas. The time factor does not influence the amount of adsorbed gas. Thus the amount of gas adsorbed per unit of surface varies within rather narrow limits. The time factor does affect the amount of catalytically transformed gas. Where the gas is transformed into a non-gaseous product, there will be an accumulation of this product in the soil in time. Thus any method which determines

the amount of non-gaseous product produced from the adsorbed gas will show more of this product in older formations over reservoirs than in younger ones over reservoirs. This is not true of methods dependent on analyzing the adsorbed gas.

FASH [resuming informal discussion]: After I had worked that out, I wanted some confirmation of it. It sounds good to me, anyway, but I wanted to have it confirmed, and about the most difficult thing I could think of was glass.

I had read somewhere, some time, that glass would allow gas to go through it. So I wrote to a professor of physics at Iowa State College, Ames, Iowa, with whom I am acquainted, who was formerly with the research laboratory of the General Electric Company at Schenectady, working with Dr. Coolidge in the development of X-ray tubes which, of course, involves the migration of gas through glass. I asked him the question, "Does gas migrate through glass and, if so, is there any explanation of the method of how it migrates?"

I won't give you the whole letter. He gave me a number of references to the literature, where it is well recognized that gas does migrate through glass. I will read the one part of the letter which is pertinent to the subject at present, in regard to the migration of gas through glass.

> The older theory stated that the gas was first adsorbed on the surface. This adsorbed layer was next dissolved in the glass and diffused to other surfaces where it evaporated. The more recent theory, outlined in reference given second, indicates that the gas molecules enter orifices in the lattice of the glass and slowly wend their way down such channels until they reach other surfaces. It takes a certain amount of energy to overcome the potential barrier at the opening, and once the gas molecule is in the opening in the lattice, it binds itself to certain groups, and then is loosed only to bind itself to another group further on. By continuing this process, the molecule slowly threads its way to the surface.
>
> Since the speed of migration of the gas molecule will depend upon the number of times it gets bound up and how long it stays bound before being loosed, it follows that the molecule which has the least attraction for the atoms in the glass lattice will be the one to get through quickest. This is the explanation offered for the very rapid diffusion of helium.

Following is a list of some of the articles on the movement of gases through glass.

J. Am. Chem. Soc. 54, 3887–901 (1932). Wm. D. Urry—Rare Gases I. The Permeability of Various Glasses to Helium

Jour. Chem. Phys. 6, 612–19 (1938). Nelson W. Taylor and Wm. Rast—The Diffusion of Helium and Hydrogen through Pyrex Chemically Resistant Glassware

Can. J. Research 8, 463–67 (1933). E. F. Burton, E. O. Braaten, and J. O. Wilhelm—Diffusion of Helium through Quartz: Relation to Temperature

Phil. Mag. 15, 1035–48 (1933). T. Alty—Diffusion of Monatomic Gases through Fused Silica

J. Phys. Chem. 36, 2595–2600 (1932). Lin Sheng T'sai and T. R. Hogness—Diffusion of Gases through Fused Quartz

J. Chem. Soc., 378–86 (1934). Richard M. Barrer—The Mechanism of Activated Diffusion through Silica Glass

J. Am. Chem. Soc. 57, 2714–17 (1935). E. O. Braaten and G. F. Clark—The Diffusion of Helium through Fused Silica

Kolloid-Z. 75, 37–39 (1936). Tominosuke Katsurai and Kensuke Kawashimo—Several Problems in Diffusion Theory

J. Soc. Chem. Ind. 58, 142–46 (1939). Burrows, Moore and Richard Brown—Diffusion of Air through Translucent Fused Silica

Glass Ind. 19, 455–56 (1938). W. Weyl and A. G. Pincus—Role of Gases in Glass IV. Miscellaneous Gases

J. Am. Chem. Soc. 44, 2160–67 (1922). G. A. Williams and J. B. Ferguson—The Diffusion of Hydrogen and Helium through Silica Glass and Other Glasses

We thus have a confirmation of the idea that gases can follow along adsorption films of gas. I believe that a reasonable explanation of the fact that we do get indication of buried oil pools at the surface directly above the oil pool can be based on the idea of the film migration of the gas.

RICHARD POMEROY: In what way is the diffusion along adsorption surfaces superior to a theory of simple diffusion through the interstitial liquid?

FASH: If the diffusion of gas occurred through the interstitial liquid rather than along the adsorbed film of liquid, more gas would be required and, in addition, if the water were flowing underground the gas could appear in the samples of soil near the surface of the ground at a point not over the oil pool. So far, results of analyses of soil samples indicate that the samples of soil above the oil pool contain the catalytic products of gas emanating from the pool. The film diffusion of the gas seems to satisfy conditions as found.

QUESTION: Why should not all sediments below surface gas manifestations be completely saturated by adsorbed gas? Rosaire's well-cutting analyses seem to show they are not.

FASH: I don't know what Rosaire's method of analysis shows in regard to the total amount of gas that can be obtained from the well cuttings. As I understood, there was a variation in the composition of the gases he determines and not the quantity of the gases. The quantity of gas is a function of surface, temperature, pressure and the gas itself and, as is stated in the article, the quantity of the gas adsorbed varies within very narrow limits. The composition of the gas, I believe, is what Dr. Rosaire determines.

ROSAIRE: No, I determine the amount as well as the composition. I showed in one of the logs the total hydrocarbons present, and then those were broken down into, first, a methane log; second, a gas log from methane through butane; and, third, a distillate log, which included those hydrocarbons from butane on up to, approximately, undecane.

Those analyses were all performed at room temperature and, as a result, the only hydrocarbons which we could measure were those which had an appreciable vapor pressure at room temperature. A heavy crude oil or wax could be run through and show no results whatsoever. So we measured both the amounts, and the composition as well.

FASH: Would the amount of gas be approximately the same,varying only in composition?

ROSAIRE: No, they vary both in composition and in amount.

QUESTION: You stated that "time has no effect on accumulation of adsorbed gas." Please explain why. One might expect that equilibrium conditions of gas migration persisting over geologic time would lead to a saturation condition in the adsorption.

FASH: When a surface is in contact with gas there is a fixed amount of adsorbed film, depending on the type of surface, the gas, temperature, and pressure conditions. This is satisfied immediately. Time will not increase the amount of the adsorbed layer.

QUESTION: If the theory of gas migration by adsorption is correct, why do we find halos over oil accumulations? Should we not find a uniform, high concentration over the entire pool?

FASH: The migration of gas from an oil pool through the adsorbed film would result in a uniform distribution of the gas at the surface of the ground, but, if you will remember, I indicated that the method I am using is a result of the catalytic action of the soil through time. Now you have surface action which, of course, for all practical purposes, we can assume is the same, but you have a variation in the composition of the soil. The soil varies in composition so that the catalytic action will vary according to the composition of the soil through which the gas passes and, as I visualize it, the product we determine at the surface of the ground is dependent not upon the way the gas escapes from the oil pool, but is dependent upon the catalytic effect the gas encounters in its progress to the surface. Thus you will have the variation in the composition of the gas at the surface but I don't believe that variation at the surface means anything, in that I don't believe it reflects any halo effect underground.

QUESTION: If the gas rises along the film of adsorbed gas on the film of the sedimentary particles, why should you get a halo effect at the surface? Or do you?

FASH: In the process of analyzing soils which I use, the product determined would be uniformly distributed in the soil over an oil pool if the catalytic effect of the sedimentary particles encountered by the gas in its upward migration from the pool was uniform. Since the catalytic effect is non-uniform, variations in the substance I determine are obtained. These variations bear no relation to the outline of the oil pool. The variations are an accident, and if a halo is obtained it is an accident.

QUESTION: What is the product or products of catalysis to which you refer?

FASH: Sorry, I can't tell you. Our process is in the Patent Office, and we have had three Patent Office actions on it. When the patent is granted, you will know what it is.

QUESTION: Are there any oil fields over which you do not find a concentration of your particular hydrocarbons?

MCDERMOTT: I will say yes. I can't explain why, and I regret the fact more than the questioner does.

BEN B. COX: On how many proved fields have soil analyses failed to outline fields?

ROSAIRE: In those cases where we have been satisfied with the quality of the sampling, and where our present analytical procedure has been used, we have found that the outlying zone of higher soil hydrocarbons is closely related to the limits of production, where defined without question by contemporary development or by development which took place subsequently. As yet we have to find a well established exception to that experience.

BEN B. COX: What new oil fields have been discovered so far by soil analysis alone?

ROSAIRE: At the Stroud prospect, southeast of the Sac and Fox pool, in Oklahoma, a test was drilled (Burke-Greis and Deep Rock's Vanderslice No. 1) which was completed, April 21, 1939, in the Prue sand for an initial production of 4 million cubic feet of gas per day, pressure, 1,200 pounds. Subsequently, a second gas well in the same sand (Sunray's Harris No. 1) has been completed.

This discovery is credited outright to geochemical prospecting by soil analysis. The accumulation is in a pinch-out in the Prue sand at a depth of 2,841–2,902 feet.

In another case, in South Texas, a material and almost completely separated extension of more than a mile has been made to sand-lens production following the determination by soil analysis of a typical ethane halo. (Fig. 2, p. 1404.)

The importance of these two discoveries goes far beyond the commercial value of the production there established, for these are discoveries of true stratigraphic traps, heretofore possible only by the use of the drill.

The shallow depths at which these discoveries were made, and the type of associated trap (overlap and sand lens), indicate the potentialities inherent in the revision of our exploration grand tactics (from structural to stratigraphic prospecting) now impending and made possible only by the introduction of microscopic geochemical prospecting.

The same laboratory procedure applied to the analysis of cuttings obtained from routine drilling resulted in the geochemical well log which is given entire credit for the discovery of East Bernard field in May, 1940. The operator, Mr. H. C. Cockburn, had issued orders to abandon on reaching the contract depth of 8,000 feet. On the basis of the favorable predictions in the geochemical well log available down to that point, Mr. Cockburn reconsidered his orders to abandon the test, and authorized further drilling. That well is now producing gas and distillate from a depth of 8,074–8,089 feet, about 70 feet below the point at which that well was officially "abandoned." Incidentally, this discovery well ran about 70 feet lower structurally than a dry hole about 5,000 feet away, and is producing from a sand which is new to the area and to the formation. (See geochemical well log, Fig. 7.)[3]

This insistence upon outright discoveries to be credited to microscopic geochemical prospecting distracts attention from the very important contributions which have been made in defining the limits of already established production. From a prospecting viewpoint, that contribution, though second in importance to that of discovering new fields, still is of major importance, for the greater part of the additional reserves credited to 1939 were additions and extensions to previously established production.

At the Turkey Creek oil field, Nueces County, Texas, with one zone already producing, a second pay zone was predicted from a soil-analysis survey, and confirmed by subsequent drilling. Other extensions to and satisfactorily accurate determinations of the limits of established production have confirmed predictions based solely on geochemical prospecting by soil analysis, notably in California at Rosecrans, Greeley, and Montebello; in the Gulf Coast, at Eureka, Hastings, Friendswood, and Reynolds; and in Oklahoma, at Ramsey.

[3] E. E. Rosaire, "Geochemical Prospecting for Petroleum," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 24, No. 10 (August, 1940), p. 1418, Fig. 7.

S. G. ELDER: How do you account for the failure of soil-analysis prospects in the Illinois Coal Basin?

ROSAIRE: You are not the only one who is worrying about that. We attribute those failures to two factors, first, inadequate geochemical control (survey density too low), and, second, an inadequate understanding of the phenomena involved. The second shortcoming followed from our previous but possibly erroneous assumption that the halo leakage was uniform in its composition of the individual hydrocarbon constituents. The recognition of this non-uniform composition has indicated the advisability of relying on the sum of the concentrations of several carefully isolated and significant hydrocarbons rather than on the concentration of individual constituents.

The recognition of this non-uniform leakage (of individual hydrocarbons) is a recent development which has taken place since the Chicago meeting, and has materially improved our interpretation procedure not only in Illinois, but also in the Gulf Coast and California.

P. J. RUSSELL: Why are not oil and gas micro-seepages trapped in overlying blanket water sands?

ROSAIRE: In many cases, they probably are, and may be represented by the non-commercial accumulation (shows) frequently reported in the sands overlying a petroleum deposit.

MCDERMOTT: Probably a portion of these micro-seepages are. Observational data indicate enough gets through to detect.

QUESTION: Are gaseous hydrocarbons found without the presence of liquid or solid hydrocarbons or *vice versa?*

MCDERMOTT: Generally all types are found but in different relative quantities.

ROSAIRE: I assume that the question refers to the analysis of soil samples. Again, I can not answer categorically, and can only describe our experience.

Our standard analytical procedure has been that in which we rely on the recognition and measurement of those hydrocarbons which display an appreciable vapor pressure at room temperature. As a routine procedure, we have avoided the use of degassing temperatures above 100° Centigrade, so as to avoid the adverse results of "cracking" certain to occur at higher temperatures in organic-bearing soils. Further, we eliminate, as probably non-significant impurities, several volatile constituents such as unsaturated hydrocarbons, organic acids, amines, etc.,.relying on the saturated hydrocarbons and some of their oxidized, condensed, and polymerized compounds.

Extraction by solvents has been used, and several liquid and solid constituents have been recognized which, under favorable conditions,[4] yield apparently significant patterns. In their physical properties, some of these extracted constituents resemble hydrocarbons; chemically, however, they are not true hydrocarbons, apparently being complex molecular compounds, resembling fatty acids and their salts. As yet, we do not know their molecular composition, let alone their origin or method of formation.

As a rule, these liquid and solid "pseudo"-hydrocarbons display high

[4] L. Horvitz, "On Geochemical Prospecting," *Geophysics*, Vol. 4, No. 3 (July, 1939).

background values, and so are markedly different from the unique origin hydrocarbons, the saturated hydrocarbons of molecular weight higher than methane (which generally display low or negligible background values).

QUESTION: If there is an increase in the amount of hydrocarbons as the oil sand is approached, as presented by Rosaire, does that not indicate a clogging of the pore spaces by these hydrocarbons and a consequent slowing down or complete stoppage of the upward migration of the gases?

ROSAIRE: The questioner undoubtedly refers first, to the "step increase" shown, by geochemical well logging, as generally present in the sediments several hundred feet above the producing zone; and second, to the hypothesis advanced by McDermott that the halo originates because the pore spaces of the shales over the accumulation are "clogged" by hydrocarbons which thus eliminate further leakage.

The problem can be restated thus. Given a bottle of crude oil, saturated with natural gas, to be sealed tightly, under pressure, without free space between the stopper and the fluid. The choice of a stopper lies between two corks, identical except that one of the two available is saturated with crude oil exactly the same as that already in the bottle.

Granting that either cork will be a satisfactory stopper for all practical purposes, which cork will, over a period of years, permit less leakage of the crude oil or the dissolved gas?

The cork which is already wetted by the crude oil will function like a wick in a kerosene lamp, and so, obviously, will be a *less* effective stopper over that period of time which the cork (that not saturated with crude oil) requires to become saturated (as it will, eventually), with the crude oil. After a time, other things being equal (the amount of oil required to saturate the cork being negligible compared to the volume of that in the bottle), the rates of leakage, though presumably small, will be equal.

Similarly, the rate of evaporation from a bottle or vessel of pure water at $-4°$ Centigrade will not be decreased by a stopper or cover of ice in equilibrium with the water, for both have the same vapor pressure.

Again, a blotter unglazed on both sides, even though saturated with ink, would not impede leakage to another similar overlying blotter in close contact with the first blotter. However, if the first (the underlying) blotter were glazed on its *upper* side, then the leakage of the ink to the overlying blotter would be reduced. That impediment to leakage of the ink would follow, not from the clogging of the blotter pores by ink, but from the lower permeability of the *glazed* upper side (cap rock?) of the underlying blotter.

QUESTION: Why should the unsaturated hydrocarbons remain unsaturated on their trip to the surface? It seems extremely unlikely that they would for an appreciable length of time. The transportation ability of the gases mentioned is, in itself, evidence of the instability of an unsaturated state. What is the possibility of contamination from drilling instruments?

MCDERMOTT: I agree. I think it is rather surprising that unsaturated gases should be present there at all. As a matter of fact, they are present in rather small quantities. I fail to see the connection between the transportation ability of the gases and their instability. Precautions have been taken to make the possibility of contamination from the drilling instruments nil.

We are not measuring unsaturated gases. We are measuring a heavier hydrocarbon constituent. How it is formed, I don't know. I am merely saying that it is easier to explain its formation by assuming the presence of unsaturated gases than it is by having to assume that the saturated gases polymerize under the conditions that exist in the earth, although, of course, you can always beg your way out by saying we have a whole lot of time, and that may make a difference.

R. V. WINN: What products of catalysis that you refer to as hydrocarbons have been identified? What is the concentration of ethylene in petroleum? Is there any further evidence of catalysis?

MCDERMOTT: As far as catalysis is concerned; as far as the general question of the synthesis or, in the narrow sense, polymerization of constituents of the lighter gases into the heavier ones by catalytic action is concerned, there are many commercial uses, as a matter of fact, to which that is put. The principal catalyzers used in the petroleum refining industry are clays, especially fine clays in that case. Aluminum chloride is used commercially as a catalytic agent to manufacture high-grade lubricating oils from the unsaturated gases. However, it is interesting that the principal catalytic agent used in the petroleum refining industry depends apparently more on surface catalytic effect than on anything else. It seems that the products of catalysis are wide in range. There may be a continuous spectrum of such products from light gases to heavy waxes. We have only commenced the complete analysis of such products. It should be remembered that no one has as yet completed the analysis of crude oil itself.

We have obtained 5,000 p.p.b. by weight of ethylene from crude oil under a vacuum at normal temperature.

R. T. SANDERSON: Has it ever been shown that no elements other than hydrogen and carbon are present in the "liquid hydrocarbons" which you consider significant?

ROSAIRE: Our analyses are based on the results of combustion, and the only products of combustion we observed are carbon dioxide and water. So I don't see how there can be anything else in there originally but hydrogen and carbon. In the case of oxidized components, of course, there is some oxygen present, but that came, we think, secondly.

So far as we are concerned we are working with materials which are pure hydrocarbons. The chemical hurdles we have set up in our analytical procedure are such as to preclude the presence of anything but ethane, propane and butane.

MCDERMOTT: I am not at all certain there may not be something besides just hydrogen and carbon. I do feel that hydrogen and carbon predominate. Whether or not there are small quantities of other elements, such as oxygen, is probably of academic importance and we probably may, some day, find out, but to date we haven't.

Chairman LEVORSEN: The other day I listened to a most interesting discussion of the chemistry of petroleum by Mr. Harold M. Smith, from the Bureau of Mines, Bartlesville Station, and he has agreed to say a few words about the chemistry of petroleum as it applies to this problem we are discussing. I would like to ask him to come to the platform and define some of the

terms we have heard this evening, such as ethylene, saturated and unsaturated, polymerized, and so forth.

Mr. Smith has had a wide experience in the chemistry of petroleum and all of its products, and I am sure he speaks with authority on the subject.

HAROLD M. SMITH: I should like to make it plain that I am not entering into any controversy here at all. I can't afford to do that.

There is one rather interesting fact that it seems to me should be considered in connection with petroleum, however, and that is that, so far as I know, all the researches that have been made on the hydrocarbons in petroleum, including the very exhaustive study by the A.P.I. group of the Bureau of Standards which has been going on for about 15 years now, have never to my knowledge found any hydrocarbons that are unsaturated or are condensed or polymerized derivatives of unsaturated hydrocarbons. All the hydrocarbons that are found, as a rule, may be divided into three classes. We have the paraffines, or chain hydrocarbons which simply consist of the carbon atoms linked together chain-fashion, with the appropriate number of hydrogen atoms attached thereto so that they are what we call saturated. If you passed gases, such as ethane and propane, which are gaseous examples of paraffines, over a catalyst in the presence of hydrogen under such conditions that hydrogen could be added if they were reactive, they would take up no hydrogen. Gases of that character can be passed over clays or other catalytic material, and unless the temperature is sufficiently high so that a dehydrogenating reaction takes place and knocks off some of that hydrogen, nothing happens. In other words, they don't polymerize, and don't condense. In order to make them form heavier hydrocarbons, drastic conditions are required to break them into unsaturated hydrocarbons, such as ethylene, which under proper conditions with catalysts, or without catalysts, with relatively high temperatures and pressures, will condense to form other hydrocarbons. If they do that, you will find the hydrocarbons they form also are unsaturated and, under proper conditions, will add hydrogen.

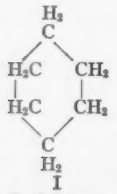
So far as I know, I have never seen any gas analysis of natural gas that is authentic, and for which the methods of analysis were given, that showed the presence of ethylene or propylene, or any of those unsaturated hydrocarbon gases. There are a number of chemists in the audience. Maybe I am in error. I just say I have never seen that.

The only approach to that, so far as I know, is that benzene, which is a cyclic compound and furthermore is not a gas, and not an unsaturated compound, as we ordinarily consider one, has been found in minute traces in gases coming from oil production. I am rather surprised that nobody has used that, because it might be a possibility.

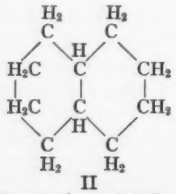
(Blackboard) Just to illustrate what I have been talking about, let's put a straight chain hydrocarbon on the board. These are called paraffines.

$H_3C–CH_2–CH_2–CH_3$. That would be butane. Butylene will have another formula, $H_3C–CH_2–CH=CH_2$. That is known as an unsaturated hydrocarbon and might be formed by two molecules of ethylene reacting, but this could be hydrogenated and would give this: $H_3C–CH_2–CH_2–CH_3$ butane. As far as I know, a compound like this butylene has never been found free in crude oil or in the gases associated with crude oil.

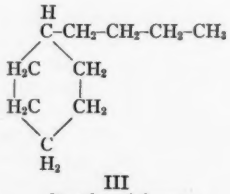
Another compound that is found in crude oil is of the type we call naphthenes. A simple one is I, cyclohexane:



I
Cyclohexane



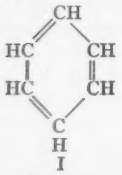
II
Decahydronaphthalene



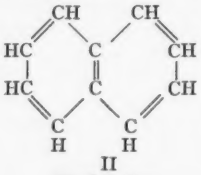
III
Butyl cyclohexane

The carbons are hitched together in rings, and that type of compound is, likewise, unreactive. I might say that the chain type is found predominantly in the light fractions, that is, gasoline and kerosene, and again occurs as solid wax in other portions of the oil. Lubricating oil, as such, has no liquid material of the paraffine type. Naphthenes are found in gasoline and kerosene, and probably constitute a large portion of the lubricating oil. These rings may be joined together so that we have several rings, as II, decahydronaphthalene, or in place of one of these hydrogens we can substitute a compound like this, III.

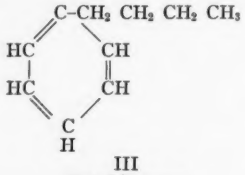
The third type of hydrocarbons we find is called aromatics. They are typified by I, benzene or benzol.



I
Benzene



II
Naphthalene



III
Butyl benzene

While that has double bonds in it, it is surprisingly stable and a great deal of heat is required to decompose it. If you heat this type of hydrocarbon (butane) high enough, you end up with a certain amount of this material (benzene).

You can likewise add on another ring here, similar to the naphthenes, giving II, naphthalene. You can add on side chains consisting of chain hydrocarbons, giving III, butyl benzene. Those two types of hydrocarbons, paraffines and naphthenes, so far as indicated by the research we know at present, constitute a large portion of petroleum. No evidence has been found for the presence of material of this type (butylene), or material that would result from these by polymerization, and would still have double bonds or unsaturation.

Chairman LEVORSEN: Thank you, Mr. Smith.

MCDERMOTT: I am not familiar with all the methods of separating the hydrocarbon gases that are in commercial use, and I admit there is very little difference in vapor pressure between ethane and ethylene, but I do want to say most emphatically that I am convinced we have separated out ethylene in crude oil.

LOUIS FRANKLIN: You insist that you have found appreciable quantities of ethylene in natural petroleum and Mr. Harold Smith of the Bureau of

Mines states that unsaturated hydrocarbons were not found. This is important. Will you describe the laboratory technique so that it may be compared with known rigorous laboratory procedure?

McDERMOTT: Ethane and ethylene were separated by fractionation. As their vapor pressures are close together it was necessary to use multiple traps. The procedure was checked by using known mixtures of ethane and ethylene.

QUESTION: Have you ever systematically analyzed samples from the same area under different conditions of rain, frost, dry spell, wet spell, etc.? Such tests should be made over a period of a year or more and at least every month or so.

ROSAIRE: Some such tests have been made, but I am familiar only with tests, on several areas, made in the "wet" and "dry" seasons of the year, but not to anywhere near the extent mentioned.

In such wet season-dry season comparison, we observed the seasonal variations previously recorded in the literature.[5] In general, the dry season is marked by a low ratio of the concentrations of ethane-propane-butane compared to the concentrations of their oxidized form "pseudo-hexane," while the wet season is marked by high ratios for the same soil constituents. This climatic variation is reduced materially by taking soil samples at greater depths, preferably below the water table.

QUESTION: What percentage of the fields over which soil analysis work has been done show the typical "halo" relationship?

ROSAIRE: Without exception, our experience has been that the typical pattern for the significant, saturated hydrocarbons is that of the halo, that is, higher concentrations generally observed around the limits of the productive area. Not infrequently, the "bald spot" within the halo is interpreted by (often irregular) patches of concentrations as high as, or often higher than, those which make up the halo.

McDERMOTT: All fields in gently folded areas show edge leakage. I believe the term "edge leakage" more desirable than "halo" as in general a complete "halo" does not occur.

M. L. NATLAND: In California oil fields no observable mineralization occurs over the oil deposits. In view of this, why do halos occur over these fields?

ROSAIRE: This premise is not correct. The geological literature records at least one instance where surface "mineralization" has been observed over California fields.[6] Further, I have seen geophysical data which indicate that the "mineralization" associated with the California oil fields is similar to that observed in Illinois, the Gulf Coast, the Permian basin, and California. Further, if no "mineralization" occurred over California oil fields, the structural predictions from reflection-seismograph data should agree with the actual subsurface more closely than they do. It is my understanding that California structures usually show more relief after drilling than was predicted by reflection-seismograph data.

[5] E. E. Rosaire, *The Handbook of Geochemical Prospecting*, p. 53. Leo Horvitz, "On Geochemical Prospecting—I," *Geophysics*, Vol. 4, No. 3 (July, 1939), pp. 210–28.

[6] J. A. Taff, "Physical Properties of Petroleum in California," *Problems of Petroleum Geology* (Amer. Assoc. Petrol. Geol., 1934), pp. 196–97.

QUESTION: Have any halos been worked out over a domal prospect by taking samples at, say, 500 feet, 200 feet, and at the surface? If so, do the respective halos center over each other or are they displaced laterally? If so, what is the amount of displacement? Has the same been done over any stratigraphic prospect located on a monoclinal structure?

ROSAIRE: Not to my knowlege. The investigation proposed is one to which I look forward with great interest, as it represents the application of geochemical well logging to "slim"-hole or core-hole testing of a prospect in advance of the more expensive production test. This is a logical prospecting procedure made possible by the development of geochemical well logging.

MCDERMOTT: Complete prospects have not been worked at the depths mentioned. However data obtained in a number of deep holes indicate that so far as hydrocarbons are concerned there is no great shift of concentration with depth in gently folded areas.

This sort of investigation has not been done in the case of a stratigraphic prospect. Theoretically there should be no difference in the respect under discussion. On theoretical grounds substantiated by experimental survey leakage occurs around the free edge of a stratigraphic trap.

Exploration endeavor to date has followed previous exploration by other methods.

W. T. BORN: Can you reconcile the findings of McDermott, that mineralization occurs *around* the pool (halo), with the finds of Rosaire that heaviest mineralization occurs *over* the pool? What does the term "mineralization" mean, calcification, silicification, or what?

ROSAIRE: In 1938, when I first called attention to significant "mineralization,"[7] I recognized that the "mineralization" of ground waters would result in a lowered (electrical) resistivity, while the "mineralization" of sediments would result in induration, increased seismic speeds, and increased (electrical) resistivities. I recognized that both soluble and insoluble secondary mineralization had to be present, but, at the time, I was not in position to show case treatments illustrating separately these two forms of "mineralization."

As our experience has been extended, we have found that, in the general case, the annular mineralization (in the near-surface sediments) appears to be the secondary deposition of insolubles, in which silicification appears to play a primary part, whereas, also in the general case, the central mineralization appears to be the secondary accumulation of solubles.

The analytical problems involved are not all solved as yet, nor are they simple in nature. Some of the data already at hand indicate that we may have to revise some of our present concepts as to the nature of the (electrical) conductivity of the sediments.

M. L. NATLAND: Is it not possible that the hydrocarbons escaping to the surface come from the oil rather than the gas cap which occupies the central part of the oil field? Vertically rising hydrocarbons emanating from the oil rather than the gas cap would produce a halo at the surface.

ROSAIRE: We have relied on the determination of the saturated hydrocarbons of lower molecular weight, methane through butane. Although these

[7] E. E. Rosaire, "Shallow Stratigraphic Variations over Gulf Coast Structures," *Geophysics*, Vol. 3, No. 3 (1938), pp. 96–115.

lighter constituents are much more characteristic of the "*gas cap*" than of the underlying oil zone, still their concentrations overlying the *edge* of the accumulation generally are greater than their concentrations in the central "bald spot," overlying the central part of the accumulation.

QUESTION: If fracturing furnishes the channels of escape of gas from an oil deposit, why should there be any pattern at all—most of all a halo?

MCDERMOTT: Theoretical reasons for edge leakage are described in my paper appearing in May issue of the *Bulletin* entitled "Geochemical Exploration, etc." Important consideration is that this type of leakage pattern is an observational fact.

QUESTION: Last night most of the discussion centered around halos. It strikes me that the patterns you have observed thus far are not necessarily indicative of the patterns you will find in the future; that furthermore the pattern is not necessarily a fundamental consideration. Granting leakage, there is no guarantee that all pools will leak in the same way. In fact it seems unreasonable to expect any particular pattern when we know that oil accumulates under so many different stratigraphic and structural conditions. Are not the chances good that you will find any number of significant patterns as more data are collected? Would it not be as great a tactical error for a geochemist to stress a particular pattern to the exclusion of others as it would for a geologist to look for structural traps and ignore stratigraphic traps?

ROSAIRE: This question is proper and most timely, striking at the crux of the whole matter of the interpretation of geochemical data. Several points are involved, as follows.

A. Is the halo pattern a special case, so rare as to have escaped attention in the past?

B. On the other hand, is the halo the general case, susceptible of infinite modification, as the anticlinal theory has been extended to cover the innumerable ramifications of the ways in which petroleum accumulation is known to occur? There we find each field a special case, each, however, conforming to the fundamentals recognized long ago, a source, a reservoir rock, and a local trap.

C. If the halo is the general case, then why was it not observed before in the days when megascopic geochemical prospecting was making its discoveries?

My presentation of the case for geochemical prospecting was aimed at a broadening of its scope beyond soil analysis alone. I endeavored to show that, even *when structural modification of the overlying beds could be neglected* (the case of a relatively deep-seated, low-relief accumulation), the columnar section above the accumulation displayed anomalous properties, in which the halo or annular pattern could be recognized by any one of several measurements.

At least some of the earlier prospectors using megascopic geochemical prospecting in the Gulf Coast had recognized the halo or aureole pattern displaced by significant gas seeps.[8]

[8] Wallace E. Pratt and L. P. Garrett, personal communications. Mr. Garrett has pointed out that his map of the Goose Creek oil field, *Geology of Salt Dome Oil Fields* (Amer. Assoc. Petrol. Geol., 1926), p. 547, was drawn on just such an annular distribution of gas seeps.

The "Eltran" anomaly shown at the Bancroft oil field[9] is a type case of a geoelectrical halo. The credit for recognizing the definite tendency for concentricity in these geoelectrical patterns goes to Mr. I. J. Fenn,[10] who first recognized that pattern in some Illinois Eltran data. Subsequently, that type case has been recognized by the writer and his associates in Illinois at Loudon, Salem, Dix, Clay City, and at other oil fields; in the Permian basin at Goldsmith, Foster, and North Cowden; in the Gulf Coast at Bancroft, Wade City, Friendswood, North Crowley, Woodlawn, Welch, Segno, La Belle, Old Ocean, Van Vleck, Pledger, Ezzell, LaGloria, and at other oil fields; and also in one other major producing province in the United States, for the time being not identified.

The refraction anomaly in the sediments (essentially unmodified structurally) overlying the Turtle Bay oil field, observed several years before the field was discovered, was displaced to the south of the accumulation itself. An even better indication of annularity is the refraction anomaly shown at the North Crowley oil field.

A similar situation undoubtedly was responsible for the erroneous interpretation of shallow structure from early refraction prospecting which resulted in the location of the Marland Oil Company's dry hole located on the flank of what we know now as the Thompsons oil field, Fort Bend County, Texas.

Investigation will show that a surprising number of seismically (by refractions or reflections) located discovery wells (on deep-seated, low-relief structures) were not centrally spotted with regard to the later developments because of the unrecognized but existing lateral variations in seismic speed limits of production illustrated by the refraction case treatments.

I reproduced Minor's salinity anomaly at DeWalt (Sugarland) to show a halo pattern already placed of record. Similarly, Torrey[11] has pointed out that his initial salinity data for the water flood at Bradford[12] suggest a salinity halo in the oil-field minerals.

I have seen at least one torsion-balance map on which the isogams showed an anomalous gravity "high" around what is very probably a significant central gravity "low." The development of the gravity meter should make it possible to secure detailed gravity maps of significant gravity "lows." I consider it very probable that, not infrequently, more such cases will be found not only in gravity prospecting, but also in magnetic prospecting.

In the case of sand-lens or fault-line accumulation, the hydrocarbon halos are long and narrow, the two quite concentric zones of high concentrations separated by a narrow zone of definitely lower concentrations.[13] Occasionally, a triple halo has been suggested.

In the case of complicated structure, cut up by faulting, the halo pattern

[9] E. E. Rosaire, "Geochemical Prospecting for Petroleum," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 24, No. 8 (August, 1940), p. 1413, Fig. 6.

[10] Staff geologist, Subterrex.

[11] Paul D. Torrey, personal communication to I. J. Fenn, April 24, 1940.

[12] Paul D. Torrey, "Migration and Encroachment of Water in the Bradford Sand," *Petroleum Engineer* (February, 1933), pp. 27–28.

[13] See hypothetical cross section in E. E. Rosaire, "Geochemical Prospecting for Petroleum," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 24, No. 8 (August, 1940), p. 1427, Fig. 15.

may be less readily recognizable, but in the writer's experience, without exception, the limits of production are, as a rule, associated with higher (hydrocarbon) concentrations than the average (hydrocarbon) concentrations generally characteristic of the producing area itself. In the writer's opinion, the halo pattern is probably characteristic of most of the *geochemical* manifestations of a petroleum accumulation.

The first essential recognition of the halo pattern in microscopic geochemical prospecting was made in 1936–1937 by Dr. Leo Horvitz[14] at the Hastings oil field, in the Gulf Coast. He first secured sufficiently quantitative data for soil hydrocarbons and soil minerals to establish that the anomalous concentrations occurred there on the edge of production, rather than over production. Subsequently, that pattern has been recognized, to state specific instances, in the Gulf Coast at Friendswood, Ezzell, Eureka, Welsh, Turkey Creek, Reynolds, Sugarland; in California at Coalinga, Northeast Coalinga, Greeley, Rio Bravo, Huntington Beach, Rosecrans, Dominguez, Montebello, Signal Hill; and in the Permian basin at Goldsmith and Bennett; in Oklahoma at Ramsey, Stroud, and Sac and Fox; and in Pennsylvania at Hebron; and by other organizations at other petroleum accumulations elsewhere.

As I have pointed out,[15] the halo pattern was present but not recognized in the early prospecting by the micro-analyses of soil air.

McDERMOTT: Have found by observation over many fields that edge leakage occurs in gently folded areas. Believe "edge leakage" better term than "halo" as we very seldom find complete "halos." There is a reasonable theoretical foundation for this as there is for leakage over an accumulation in the case of steeply folded accumulations. Of course as the structure becomes complicated the ideal pattern will be modified. It is necessary to have some basis for interpretation.

JOHN L. RICH: Have you been able to race shoestring sands by means of soil analysis?

ROSAIRE: I would like to turn the answer to that question over to Mr. John Merritt. I believe his organization has done work in the shoestring sands, and mine has not.

Chairman LEVORSEN: I would like to ask Mr. Merritt to come to the microphone, as he also has done a great deal of geochemical surveying. He has still another approach to the problem, I believe, than that of some of the previous speakers.

JOHN W. MERRITT: The answer is "Yes." We have traced shoestrings. Unfortunately, our work is confidential. We have traced shoestrings with lateral dimensions of 500, or 600, or 1,000 feet in at least three or four different cases. Yes, we got a halo on both sides. The halo pattern comes very close to the Margin in the oil, and the halo pattern is generally very narrow, with a width of 300 to 500 feet at the most, in shoestring sands that varied in depth from 400 to 2,500, or 3,000 feet.

QUESTION: The following statement has often been made.

"Shale, dried at high temperature, but not fused, was submitted to several

[14] Chief geochemist, Subterrex.

[15] E. E. Rosaire, "Discussion and Communications," *Geophysics*, Vol. 4, No. 4 (October, 1939), pp. 300–06.

of the laboratories along with other samples. Hydrocarbons, in variable amounts, were found by all. Is the laboratory technique all that it might be in the way of accuracy?"

McDERMOTT: Have not made measurements of such samples.

ROSAIRE: In the preconceived assumption of infallibility in its premise, and in the categorical nature of its proposition, this question is as awkward to answer as that more familiar "When did you stop beating your wife?"

The reader is asked, first, to assume that the rather indefinite treatment described resulted in hydrocarbon-free shale; and, second, to discredit the positive analytical results, though reported by each of the unidentified laboratories. *Ipso facto*, then the inference follows that the reported existence of soil hydrocarbons is still open to question.

If this reported test is *bona fide*, and was intended as a critical experiment, then the several analytical results should be reported along with the answers to the following questions.[16] Until this is done, the statement should be discredited as being a poorly organized test. With the answers to the following questions to compare with the analytical results, any competent chemist will be able to decide whether the experimental control justified rating this test as a critical experiment.

A. What were the characteristics of the original shale sample?
   Organic content, high, medium, or low? Was it an "oil shale"?
B. What was the history of the sample subsequent to its collection and prior to the analyses?
   What was the hydrocarbon content of the shale sample prior to "drying"?
   At what temperature would the shale have fused?
   How "high" was the drying temperature? (To some of us, the boiling point of water would be high; to a glass-blower working Pyrex, the air-gas flame is cool, for he uses that flame for annealing.)
   Was the drying carried out *in vacuo*, or at atmospheric pressure?
   If at atmospheric pressure, was the "drying" carried out in an open or in a closed oven? (The latter might have permitted incomplete combustion of organic matter, with the formation, by pyrolysis, of complex end products, including hydrocarbons.)
C. What (measured) loss of hydrocarbons and organic matter took place as a result of the "drying"?
   What measurement was used to establish that the "dried" sample *was* hydrocarbon-free? Was this check on the hydrocarbon content of the dried sample as quantitative as the laboratory techniques whose accuracies are held open to question?

The foregoing rebuttal questions may seem unnecessary, but the form that this question takes, and the anonymous nature of the challenge, seem to have raised serious doubts in many minds. Are these unidentified laboratories to be considered guilty until proved innocent?

I am not familiar with the analytical procedures or the standards of accuracy characteristic of all the laboratories engaged in geochemical prospecting, but I am familiar with those maintained by my own laboratory.

I know that hydrocarbon-free material is not too readily obtainable. Dry sand from Galveston Beach, or Permian basin dune sand, is, generally, though

[16] If the details are not forthcoming, then it is obvious that this statement is cut from the same cloth as that from which "whispering campaigns" are made.

not always, hydrocarbon-free. The inclusion of minute amounts of organic matter can result in measurable amounts of methane.

Surely, one would assume "C.P." inorganic reagents are "hydrocarbon-free," yet we have found appreciable amounts of hydrocarbons in one routine shipment of a particular "C.P." reagent received from a manufacturer of excellent standing. The amounts of such contamination (including saturated hydrocarbons heavier than methane) were greater than the amounts observed in the soil samples going through the laboratory. Fantastic? But the manufacturer used natural brines for his raw materials, and did not take the steps required to insure that his products *were* hydrocarbon-free.

Our routine laboratory procedure calls for analyses of each shipment of materials used (including the distilled water) to insure that these reagents *are* hydrocarbon-free down to the established apparatus sensitivity, and, further, the hydrocarbon content of the laboratory air is checked at regular intervals.

The sensitivity is such that the apparatus can detect one part per million by volume. A paper, now in preparation by Dr. Leo Horvitz, will describe the apparatus fully, and also will give particulars as to its sensitivity and reproducibility of measurement.

If the questioner considered the reported trial as critical, then the test should have been carried out under controlled conditions, and the evidence reported fully. Does he consider that the reported treatment was as severe as that endured by lava? Yet, lava vesicles have been reported which contained visible droplets of oil. Had he submitted such hydrocarbon-bearing lava to the general treatment described in the question, and the laboratories (after breaking down the vesicular structure) had reported appreciable amounts of hydrocarbons, would he still consider the analytical methods open to question?

Under the circumstances, and in view of the rigorous analytical standards maintained in some, at least, of the geochemical laboratories, the answer to the question is that our experience is that, at present, the routine sensitivity of one part per million by volume is a satisfactory high level of sensitivity to maintain in laboratory technique.

QUESTION: How long after a well is drilled will the cuttings retain their lighter hydrocarbons in sufficient amounts to make their analysis significant?

ROSAIRE: Our experience, admittedly limited, and still qualitative, has been that cuttings, bottled immediately after collection while still wet, show a decrease in hydrocarbon content with time. In most cases, this rate of decrease is greater for the higher molecular weight hydrocarbons than for those of lower molecular weight, an established *phenomenon* for which we are not ready now to offer an *explanation* with which we are fully satisfied. Best data follow from the analyses of cuttings as soon as possible after their collection from the mud return.

This rate of (concentration) decrease appears to be diminished materially by drying the cuttings immediately after their collection. Consequently, when cuttings can not be analyzed within 48 hours after their collection, we find it advisable to dry them immediately after collection by sacking and hanging near the boilers or steam pipes. Such dried samples do *not* give results as high in quality as those secured by the analysis of cuttings immediately after collection, but, on the other hand, data of apparent significance have been se-

cured by the analysis of such dried cuttings several months after their collection.

As would be expected, and as we find to be the case, extended shelf life does not improve the quality of the resulting data. The justification for making dried-sample geochemical logs is that, in many cases, the resulting data, though not of the highest quality, contribute information of importance, and so may be better than no data at all.

QUESTION: Fresh granites have been analyzed and show an absence of hydrocarbons, yet the overlying soil shows the presence of hydrocarbons and soil gas. Would that not indicate that some of the anomalies of concentration are the result of surface phenomena and not caused by deep-seated oil accumulations?

MCDERMOTT: Have found hydrocarbons in all granite samples measured. As some hydrocarbons are liberated from vegetable matter, it is important from the viewpoint of exploration to measure a constituent which does not come from vegetable matter. Am convinced we are doing this.

ROSAIRE: Again a preconceived infallibility is present in the premise, that "fresh" granite is hydrocarbon-free. In this case, the details of collection and the analytical data should be reported for both the granite and the immediately overlying soil.

I am familiar with some, and have read of more, analyses of granites and other igneous and metamorphic rocks,[17] which showed measurable amounts of hydrocarbons.

At present, I am not interested in speculation on the source of hydrocarbons not infrequently found in the soil immediately overlying such granites.

I *am* interested in prospecting for petroleum, and to a much less extent in its origin. In attacking the latter problem, other workers have spent thereon much effort and time, and the problem is still unsolved. Of the two problems, I consider that I have a far better chance to solve the first, the location of a petroleum accumulation without regard to its origin.

If a geochemical survey results in the location of a test well in the Central Mineral region of Texas, and the interested capitalist objects to striking granite at an inadequately shallow depth, he needs some, or perhaps much better, geological advice.

QUESTION: Does cap rock fail to extend beyond oil-water contact?

MCDERMOTT: The cap rock does.

ROSAIRE: I have no actual data available with which to answer this question properly. I have been told[18] that, in the Henne-Winch-Farish oil field and other similar fields on the same trend in South Texas, the drillers report no accumulation of petroleum where no cap rock is encountered.

The geochemical origin of the cap rock was advanced here as a hypothesis, which is subject to revision if necessitated by the results of further investigation.

[17] "Symposium on Occurrence of Petroleum in Igneous and Metamorphic Rocks," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 16, No. 8 (August, 1932), pp. 717–858. R. W. Pike *et al.*, "Source Rocks of Petroleum—A Symposium of Opinion," *ibid.*, Vol. 24, No. 3 (March, 1940), pp. 496–503. F. W. Clarke, "Data of Geochemistry," *U. S. Geol. Survey Bull. 770* (1924), p. 279, pp. 731 *et seq.*

[18] Paul Weaver, personal communication.

QUESTION: Surface seeps and indications of oil led to the earlier discoveries but not the best pools of even the same areas. In other words the best productive pools may have no seeps whereas the poorer have.

MCDERMOTT: Visible seeps led to good as well as poor discoveries. These earlier methods were crude and had no quantitative foundation.

ROSAIRE: This is hardly a question, but rather a statement and, certainly is not in accord with Mr. DeGolyer's statement[19] that macroscopic geochemical prospecting was responsible for the discovery of more petroleum than was discovered by any other exploration technique. In spite of the novelty of this (Mr. White's) postulation, I am inclined to question its validity.

After we have acquired additional experience in microscopic geochemical prospecting, we will be in better position to discuss the relationship between the magnitude of the surface seepage and the magnitude of the petroleum accumulations from which they originate.

R. F. BEERS: Have you information regarding the horizontal and vertical extent of zones of mineralization?

ROSAIRE: The horizontal extent of the significant area of mineralization, like the hydrocarbon-halo effusion (to which we think the significant mineralization owes its origin), is of about the same order of magnitude as the areal extent of the petroleum accumulation itself.

We know much less about the vertical extent, although new evidence at hand indicates that, in one or more of several different chemical forms, it occupies the greater part of the sedimentary column above the petroleum accumulation.

[19] E. DeGolyer, "Future Position of Petroleum Geology in the Oil Industry," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 24, No. 8 (August, 1940), p. 1389.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 24, NO. 8 (AUGUST, 1940), PP. 1464-1474, 2 FIGS.

CRITICAL SURVEY OF RECENT DEVELOPMENTS IN GEOCHEMICAL PROSPECTING[1]

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ABSTRACT

A critical study of the respective advantages and disadvantages of the two current geochemical prospecting procedures is presented. It is particularly pointed out that soil analysis has only as advantage a relatively simple field procedure but in view of the complexity of the material analyzed, it is difficult, if not impossible, to reduce results to a common basis of comparison. Further limitations placed on soil-analysis prospecting are the persistence of the halo patterns and the shielding effect of shallow beds bearing oil and/or gas. Soil-air sampling is not affected by these limitations to as high a degree as soil sampling and it is therefore recommended that it should be given further serious trials regardless of the fact that it requires a more complex field procedure.

Geochemical methods of prospecting have sprung prominently to the foreground as promising methods of prospecting for oil and gas in recent years and they have been immediately the object of a very acute controversy, not only concerning the basic principles on which the processes are based, but particularly concerning the methods of interpreting results.

Russian research workers are generally credited as being first to have suggested the methods of micro-chemical analysis of soil constituents as a possibly new tool in the search for oil and gas structures, yet information little known indicates that G. L. Hassler in about 1930 was the first one to work at least on the idea and to attempt the realization of an apparatus which would measure minute amounts of hydrocarbon in the soil. Apparently, Hassler's apparatus and methods were unsuccessful, but shortly thereafter the Gulf Oil Corporation developed apparatus and methods of greater precision under the direction of A. J. Teplitz. Results however proved discouraging.

In the meantime, simultaneously in Russia and Germany, first results of geochemical prospecting were announced by V. A. Sokolov[3] on one hand and by G. Laubmeyer[4] on the other. These first results were enthusiastically reported to the scientific press and stirred some

[1] This article was submitted for the symposium on geochemical exploration but due to the crowded program and the inability of the author to be present, it was not presented.—A. I. L.

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[3] V. A. Sokolov, "New Methods of Prospecting for Oil and Gas Deposits," *Trudy Neftyanoi Geologo, Razvedochnoi Konferentsii* (January, 1933).

[4] G. Laubmeyer, "A New Geophysical Prospecting Method, especially for Deposits of Hydrocarbons," *Petroleum*, Vol. 29, No. 18 (May 3, 1933), pp. 1–4.

interest in this country which led the Humble Oil and Refining Company to conduct some extensive experimental surveys with apparent success. Later, R. O. Smith[5] and E. E. Rosaire[6] introduced new practices by analyzing soil samples rather than soil air.

SOIL SAMPLING

Experimental surveys in soil sampling revealed immediately that the interpretation of the results was complex and that the soil-hydrocarbon distribution was not according to an evident theory. In particular it was noted that, contrary to expectation, the largest hydrocarbon concentrations were obtained on the edge of pools. Many independent investigators have reported similar findings. Therefore a new theory was evolved, the so-called "halo theory," whereby the leakage of gases from an oil and gas accumulation would be greater on the edge of the pool. In order to justify this theory, various possibilities were invoked. One is the induration of deep and near-surface sediments by deposits of salts from the structure. According to some investigators, this finds a justification in the seemingly decreased rate of drilling over an oil-bearing structure but investigations reported privately to the writer by D. C. Barton before his untimely death deny this. Possibly, there is plugging of the sediments by deposits of hydrocarbons and salts, thus reducing the permeability of the sediments. Results which would tend to prove the validity of this theory have recently been reported by E. E. Rosaire at the February meeting of the American Institute of Mining and Metallurgical Engineers in New York but no actual measurements of average permeability have been reported; such measurements would be much more conclusive. Others have explained the halo theory on the basis that invisible cracks would render formations more permeable on the edge of oil and gas pools but no evident explanation exists as to why the cracks should be confined to the edge of structures. In brief, it seems that the halo theory is well established by experimental evidences but the explanation of the phenomenon is yet unknown. Yet, surveys have been reported where halos are not recognized in the concentration distribution; this seems to occur when the ratio of the structure's width to the depth below the surface attains a critical value below which no halo exists. Until further proof is submitted, the writer has been led to believe in the halo theory (at least where analysis of soil samples is resorted

[5] Mitchell Tucker, "Soil Analysis Surveys Being Made as an Aid in Geophysical Studies," *Oil and Gas Jour.* (June 23, 1938).

[6] E. E. Rosaire, "Shallow Stratigraphic Variations over Gulf Coast Structures," *Geophysics*, Vol. 3, No. 3 (1938), pp. 96–115.

to) by the few surveys to which he was a part, some of which are reported here as examples.

Some of the fundamental objections to *soil sampling* or "soil analysis" as it is called are here reviewed. The writer has had a limited experience with the procedure and therefore the objections raised come perhaps from a premature generalization based on an insufficient number of data; they are therefore offered here as suggestions so they may be checked by others who have access to a larger number of data.

1. In analyzing soil samples one deals with an extremely complex substance, finely divided and therefore presenting an extensive and chemically active surface on which the hydrocarbon and other gases escaping from an underground oil and/or gas accumulation are assumed to be retained by adsorption. However, the mechanism of this adsorption is not clear and the writer has some evidences that the retention of gases by the soil may be chemical in nature for the most part and that adsorption forces (the so-called Van der Walls forces) play an unimportant rôle in retaining such gases and vapors. On the basis of the adsorption theory, the writer[7] evolved a correction procedure whereby all the measurements of soil-gas content would be reduced to a common basis by means of a measurement of the degree of subdivision of the soil, that is, mainly by measuring the grain-size distribution of a soil and thereby computing the relative total surface of the soil samples. Measurements, reported to the writer by C. F. Bowden,[8] made on samples of clays of the same crystalline composition, but of varying surface chemical nature, indicate that one clay having a surface at least ten times smaller than another retained twice as much ethane, per equal weight of clay sample, when brought in intimate contact with a sample of air containing a given proportion of ethane. This is in direct contradiction with the expected results and gives ample proof that the mechanism of retention of hydrocarbons by soil depends more on the chemical nature of soils than on their degree of subdivision, grain size, exposed grain surface, and other physical characteristics. From this example, it appears that the particle size plays a secondary rôle in retaining the gases of leakage in the soil and that correction methods based solely on particle size will yield nondependable results.

Another method of reducing soil-analysis data to a common basis of comparison has been advocated by G. Bays (U. S. Patent 2,165,

[7] Sylvain J. Pirson, "A Critical Survey of the Geochemical Methods of Prospecting for Oil and Gas Accumulations," American Petroleum Institute Division of Production, Meeting of the Eastern District (April 4–5, 1939).

[8] Private communication.

440) who has suggested that the sample, after removal of its hydrocarbon content, be placed in contact with a gas of known composition and the amount adsorbed measured. It is also suggested in the same patent, that grain size be measured and the results used empirically as a correction coefficient. In view of the foregoing discussion, this can be discarded as inaccurate since grain size alone does not account for the variations in retention of hydrocarbon gases among various soils. However, the idea of contacting the samples of soil, after their analysis, with a gas of known composition, has considerable merit, particularly if this gas is air containing a small amount of the hydrocarbon or the other gases sought. Unfortunately, the method proposed leads to erroneous results if the data are used on a proportional basis. A method justifiable scientifically, as will be seen, would necessitate a tremendous amount of work and would render the process too costly for commercial use. One must remember that according to the Bays idea of adsorption, the amount of gases adsorbed by the soil should follow the well known Freundlich equation, and C. F. Bowden[9] has found by experiment that such a formula applies:

$$A = KC^{1/n} \tag{1}$$

in which: A is the amount of gas adsorbed

K and n are constants depending on the material tested.

C is the equilibrium concentration in the contacting gas.

The quantity A is usually measured in parts per billion by weight of the soil sample, the constants K and n vary with the soil samples and are characteristic of their adsorption properties. Therefore, for each sample in the survey, the following equations may be written:

$$\begin{aligned} A_1 &= K_1C_1^{1/n_1} \\ A_2 &= K_2C_2^{1/n_2} \\ &\cdots\cdots \\ A_i &= K_iC_i^{1/n_i}. \end{aligned} \tag{2}$$

The Bays patent suggests the use of a gas of a constant concentration C and the measurement of the amounts retained after contacting each sample, yielding the following relations.

$$\begin{aligned} A_1^1 &= K_1C^{1/n_1} \\ A_2^1 &= K_2C^{1/n_2} \\ &\cdots\cdots \\ A_i^1 &= K_iC^{1/n_i} \end{aligned} \tag{3}$$

[9] C. F. Bowden, "A Discussion of Factors Influencing Soil Analysis Surveys," Master of Science Thesis, Pennsylvania State College (February, 1939).

in which $A_1^1, A_2^1, \cdots A_i^1$ are the amounts of gas adsorbed. It is further suggested that these readings be used for the correction of results to a common basis, presumably by proportional reduction, as follows:

$$\begin{aligned} A_1 &= K_1 C_1^{1/n_1} \qquad \text{(Base reading)} \\ A_2^{11} &= \frac{A_1^1}{A_2^1} A_2 = K_1 C^{1/n_1 - 1/n_2} C_2^{1/n_2} \\ A_3^{11} &= \frac{A_1^1}{A_3^1} A_3 = K_1 C^{1/n_1 - 1/n_3} C_3^{1/n_3} \\ &\cdots\cdots\cdots\cdots\cdots \end{aligned} \tag{4}$$

in which $A_2^{11}, A_3^{11}, \ldots$, are the corrected readings reduced presumably to a common basis, that is, the first sample. As can be seen, this method yields erroneous results since the readings corrected to a soil having adsorption characteristics similar to sample 1 should be:

$$\begin{aligned} A_2^{111} &= K_1 C_2^{n_1} \\ A_3^{111} &= K_1 C_3^{n_1} \\ &\cdots\cdots \end{aligned} \tag{5}$$

On the basis of the Bays disclosure, a really accurate method would be to proceed as follows. By means of a series of gas samples of varying known concentrations, determine the most probable values of K and n for each sample and thereafter calculate the equilibrium concentrations: $C_1, C_2, C_3, \ldots$ of the gases in the soil air. This method would therefore give results of soil surveys on a volume basis in the soil air and the results would be equivalent to those obtained by soil-air sampling. Corrected results on a weight basis could also be obtained by means of (5). The purpose of this discussion is to point out that soil sampling, although being an extremely simple field procedure, necessitates correction factors which are at best questionable if too simple or too expensive if accuracy is required and then the results obtained are equivalent to the results of soil-air sampling.

2. A second objection which the writer makes to the use of soil-sample analysis resides in the observed fact that the concentrations of hydrocarbon in the undisturbed soil remain relatively invariable over a period of a large number of years, and, therefore, the phenomenon observed is *static* in nature and not *dynamic*. Therefore, an accumulation of oil at depth may have yielded its characteristic halo pattern at the surface of the ground in the distant past and if, for some tectonic reason, the same oil moves to another trap, the pat-

tern will still remain indefinitely. The prospector may find this halo by geochemical analysis of the soil thereafter and be misled by its finding and induced to drill a disappointing test.

Justification for such a possibility seems to have existed when the Mills Bennett Production Company's Truchard No. 1, Ed. Curbit Survey, Colorado City, Texas, was drilled as a geochemical prospect of great promise and was proved dry at a depth of 7,086 feet. Another example of such a possibility was obtained by the writer in an experimental survey over a well known surface structure in southern New York state where two wells were being drilled for Oriskany sand gas (Fig. 1). Van Gilder's Rigby well No. 1 was condemned by the survey whereas the Belmont Quadrangle Drilling Company's Baham well No. 1 was given a good chance of success, particularly in view of the perfect agreement of the geochemical survey, the surface structure, and the seismograph survey results reported to the writer by F. Brewster, president of the Belmont Quadrangle Drilling Company. Both wells were proved to be failures, leading the writer to the belief that the survey indicated a past, but dissipated accumulation, which had left its hydrocarbon halo in the surface soil to this day.

The phenomenon of the *persistence of the halo* may be the explanation for the existence of innumerable erratic and confusing patterns which are often obtained in geochemical prospecting making use of the soil-sampling procedure.

3. A further limitation of geochemical prospecting, common to both soil sampling and soil-air sampling, resides in their inherent inability to give an idea of the depth of the source yielding the surface patterns. Perhaps this limitation is more inherent yet to soil sampling than to air sampling because the latter's results seem to conform more readily to theoretical patterns than the former's.

This limitation in depth determination was beautifully illustrated to the writer when a well was drilled in the state of New York as a result of a survey made by the writer and illustrated in Figure 2. The figure represents only part of the survey in the immediate vicinity of the well location (Hanley and Bird's Vanderhoof No. 1), and represents the results of the analyses as well as the writer's interpretation. As the survey was conducted without the knowledge of any other geological or geophysical information whatsoever, it constituted an ideal test for geochemical surveys. A fairly satisfactory halo pattern was obtained although complete closure did not exist toward the northeast. The well location was therefore based solely on geochemical results and drilling operations commenced. At shallow depth, considerable volumes of gas were encountered as follows.

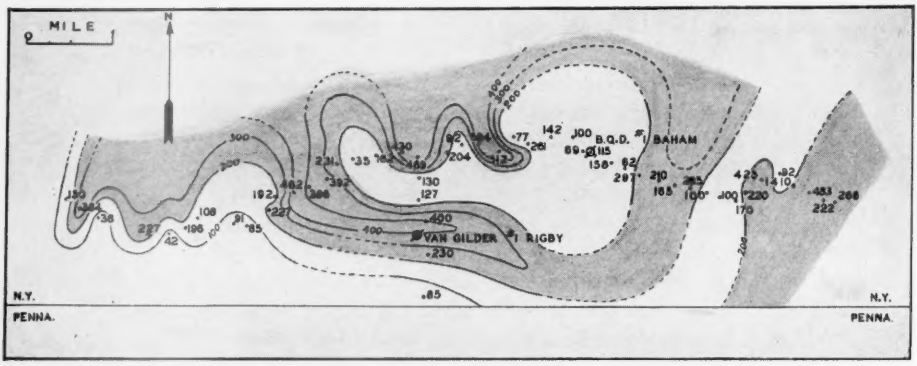

FIG. 1.—Results of soil-analysis survey in Independence Township, Allegany County, New York. Soil hydrocarbon content of top soil in parts per million by weight. Survey completed, October 10, 1939.

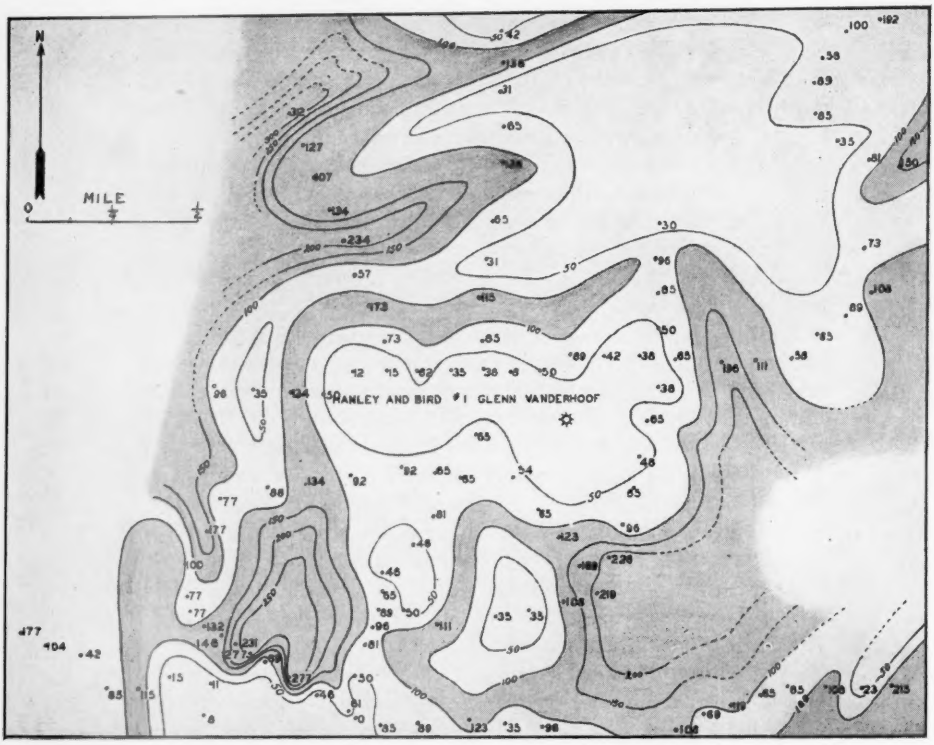

FIG. 2.—Results of soil-analysis survey in Hartsville and Canisteo townships, Steuben County, New York. Soil hydrocarbon content of top soil in parts per million by weight. Survey completed, August 15, 1939.

At 458 feet, gas in limestone: 500,000 cubic feet in 24 hours
At 1,037 feet, gas in limestone: 1,217,000 cubic feet of gas, and 4 barrels of gasoline in 24 hours. Commercial production of this shallow distillate is now reported (July 15, 1940)
At 1,185 feet, gas in shale: not gaged

After drilling was completed and the well was plugged back, the shallow-gas open flow was still 76,000 cubic feet per day and the closed-in pressure 65 pounds per square inch. The most interesting feature of this shallow production was the existence of a light distillate which, at times, filled the hole up to 400 feet from bottom. The gas pressure was however rapidly dissipated by the use of gas as a fuel for drilling deeper. The well was proved dry in the Oriskany sandstone, which was the drilling objective, but this well, nevertheless, was remarkable in being the first wildcat drilled on a geochemical prospect and in obtaining some production. This partially successful test proved that shallow accumulations have a screening effect over the possible deeper production and therefore no promise can be made as to the possible production in deep formations overlain by shallow oil- or gas-bearing strata. In the case of the present intensified search for Oriskany gas, this is a considerable limitation placed on the geochemical methods since shallow gas is practically present everywhere in pockets in the prospective territory.

A study of this survey, over an area covering about 4,000 acres around the Vanderhoof well, revealed that, in general, the geochemical trends discovered coincided satisfactorily with the known geological trends, mainly east and west. Therefore, it was concluded that shallow gas accumulations in the territory were, to a certain degree, in conformity with geological trends.

On account of these limitations of prospecting by soil-sample analysis it is the writer's opinion that it is of doubtful value unless a fast, inexpensive, and accurate correction method for variations in soil-sample character can be found, which would overcome the first limitation here described. Yet the two other limitations would still exist. For this reason, the writer is of the opinion that further development should be made in the technic of soil-air sampling upon which procedure the last two limitations are placed only to a restricted degree.

SOIL-AIR SAMPLING

Concerning the analysis of soil air, reported analyses by Russian and German workers seem to indicate that the halo theory does not exist. In fact a maximum concentration of light hydrocarbon gases is found in the soil air above the accumulations of gas and oil, unless geologic disturbances such as faulting intervene in order to complicate

the leakage phenomenon. This indicates that, when analyzing soil air, one deals with a true *dynamic phenomenon*, whereas, in the case of the analysis of soil samples, one deals with a *static phenomenon*. This has considerable bearing on the reliability of the conclusions of a geochemical survey.

Field operations in soil-air sampling are, of course, more expensive than soil sampling due to the extreme care necessary to secure representative samples and to preserve them until their analysis in the laboratory. This drawback is, however, offset by the following advantages.

1. No corrections for the nature of the soil are necessary.

2. The concentrations of hydrocarbon gases in the soil air being due to a dynamic phenomenon, the persistence of soil patterns does not exist and only active oil and gas accumulations under sufficient pressure will register in the survey. Therefore, failures of a nature similar to that observed on the structure drilled by the Belmont Quadrangle Drilling Company would be eliminated.

3. The screening effect of shallow production may be eliminated because the data from a soil-air survey may be submitted to quantitative determination of the depth to the source of the diffusing gas. The writer[10] has already published a formula which permits depth determination of a long and narrow source.

$$V = \frac{-\pi K \gamma_0 (p_s^2 - p_0^2)}{4h\mu p_0 \, ln \frac{\pi l}{4h}} \times \frac{1}{\cos h \frac{\pi \alpha}{2h}} \qquad (6)$$

in which

V is the mass velocity of efflux of the diffusing gas in gram/sq. cm./sec.
K is the average permeability of the overburden in Darcy
γ_0 is the density of the gas at standard conditions in gram/cm.^{3}
μ is the viscosity of the gas in centipoises
p_s is the pressure of the gas at the sand in atmospheres
p_0 is the atmospheric pressure = 1
l is the width of the source in centimeters
h is the depth of the sand below the soil in centimeters
α is the angle of position of the sample with respect to the axis of the source.

It was found that this formula agreed well with Sokolov and Antonov's

[10] Sylvain J. Pirson, "Ground Gas Survey Is Promising Tool," *Oil Weekly* (October 10, 1938).

formulae.[11] The writer's formula has the advantage of measuring the efflux of gas at the surface as a function of measurable quantities, in particular the permeability and, therefore, for a single producing sand structure, the depth to production may be calculated with a reasonable degree of accuracy. This depth is theoretically equal to the distance measured from the sample with maximum concentration to a sample having a concentration equal to 0.4 of this maximum.[12]

When multiple sands are suspected in the structure, a curve-fitting study of various geochemical cross sections may permit the separation into curves due to individual sands and thereby permit a predetermination of the depth to each sand.

Knowing the approximate depth to an accumulation the probable reservoir pressure may be calculated from formula (6) and thereby yield a further check on the depth calculation since reservoir pressure is generally and substantially equal to the hydrostatic head, above the producing zone. Sokolov[13] has reported that preliminary experiments have shown that the gas overall permeability of moistened rocks is of the magnitude of 10^{-7} Darcy. Applying formula (6) to an overburden 1,000 meters thick over a shoestring sand 100 meters wide, and considering pure methane of a viscosity of 0.0185 centipoise, a reservoir pressure of 100 atmospheres absolute, the efflux of methane would become:

$$V = \frac{-\pi \times 10^{-7} \times .5544 \times .0012 \times [(100)^2 - 1]}{4 \times 100{,}000 \times .0183 \times 1 \times ln\left(\frac{\pi \times 100}{4 \times 1000}\right)}$$

$$= 1.7 \times 10^{-4} \text{ mm.}^3 \text{ per cm.}^2\text{/sec.}$$

In order to obtain the soil-air concentration, it would be necessary to take into account the "soil-breathing effect" whereby the soil air is continuously renewed by atmospheric air.

Now that the advantages of soil-air sampling over soil analysis have been pointed out, it is also of interest to consider the difficulties encountered by soil-air analysis prospecting.

1. Representative soil-air samples may not be obtained where the soil is water-logged; that is, in swamps, river beds, and coastal prospects.
2. Air samples are difficult to obtain where hard rocks crop out.
3. Soil breathing varies from place to place according to soil po-

[11] Sylvain J. Pirson, *op. cit.*

[12] C. F. Bowden, *op. cit.*

[13] V. A. Sokolov, *Gas Surveying*, p. 28. Moscow (1936).

rosity and variations in atmospheric conditions; therefore, sampling must be done at a reasonable depth.

4. Concentrations of hydrocarbon gases in the soil air are small and special precautions must be taken so that hydrocarbon gases will not be preferentially adsorbed by any part of the sampling device. Hydrocarbon gases are also soluble to a certain extent in water and other liquids, and bubbling soil air through such confining liquids must be avoided.

5. The suction applied to remove a sample of soil air must not be large, otherwise adsorbed hydrocarbons may be removed from the soil particles, by pressure reduction.

In view of these difficulties, soil-air sampling has been altogether discarded by American investigators as far as the writer knows; it seems however that the difficulties are not altogether unsurmountable and that the procedure deserves further investigation in view of its advantages over soil sampling.

ACKNOWLEDGMENTS

The writer wishes to thank C. F. Bowden for information concerning the rate of gas adsorption relative to two clays of identical mineral composition and varying surface characteristics; Chester D. Whorton, geologist with Godfrey L. Cabot, Inc., of Wellsville, New York, for collecting the samples relative to Figure 1, and for furnishing surface geologic information on this prospect; and F. E. Eckert, of Hanley and Bird, Bradford, Pennsylvania, for furnishing information relative to the Vanderhoof well and for permission to publish Figure 2.

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GEOLOGICAL NOTES

HYDROGENATION OF OIL: SUGGESTED NATURAL SOURCE OF HYDROGEN[1]

E. T. HECK[2]
Morgantown, West Virginia

During the course of studies of the reactions involved in the origin of the saline waters associated with petroleum the writer has been intrigued by a series of reactions that apparently yield hydrogen. These reactions involve the reduction of sulphate to sulphide, and the "fixation" of the sulphur in the disulphide FeS_2. The reduction of sulphate is discussed in nearly all papers on the origins of black muds and Ginter[3] has reviewed the subject for sub-surface waters. Some writers insist that bacteria are necessary for the reductions of sulphate. While bacteria are probably present in the case of surface reactions during deposition, just how long the bacteria survived after burial is problematical. However, as Ginter[4] says, "The consensus of opinion is that sulphates in sub-surface waters have been chemically reduced by some agent." The exact mechanism of the reduction is not known but the results may be illustrated as follows.

(1) $CaSO_4$ + organic matter = $CaCO_3 + H_2S + H_2O$ + organic matter

The H_2S is thought to react with iron as follows.

(2) $FeCO_3 + H_2S = FeS + H_2CO_3$

These reactions are usually given for the common occurrence of FeS in black muds. Since FeS is not known to occur normally in ancient sediments it has been suggested that in the course of diagenesis the FeS is converted to FeS_2.[5] FeS_2 is perhaps the most common and universal authigenic mineral associated with petroleum, and a few have gone so far as to suggest that pyrite and petroleum are genetically related. In spite of this, illustrative reactions for the formation of FeS_2 in sediments are very scarce. In fact, illustrative reactions for the formation of FeS_2 from FeS in sediments have not been found by

[1] Manuscript received, June 7, 1940.

[2] Assistant geologist, West Virginia Geological and Economic Survey.

[3] R. L. Ginter, "Sulphate Reduction in Deep Subsurface Waters," *Problems of Petroleum Geology* (Amer. Assoc. Petrol. Geol., 1934), pp. 907–25.

[4] *Ibid.*, p. 908.

[5] F. H. Hatch, R. H. Rastall, and M. Black, *The Petrology of the Sedimentary Rocks*, London (1938), pp. 287 and 293. See also W. H. Twenhofel, *Principles of Sedimentation*, McGraw-Hill Book Company, Inc. (1939), pp. 303 and 396.

the writer. A purely illustrative reaction for the formation of FeS_2 from FeS may be written as follows.

(3) $FeS+H_2S=FeS_2+H_2$

The sulphate-sulphide-disulphide series may be written with various intermediate reactions, but if the series is valid it would seem that the equivalent of hydrogen is produced somewhere along the line. It is not postulated that all FeS_2 is formed after the burial of the sediments, but it is reasonably certain that some of it is. Evidence for the above is the continued reduction of sulphate, the apparent disappearance of FeS and the interstitial form of some FeS_2.

It is probable that there are several intermediate reactions instead of just one for the formation of FeS_2 from FeS. H_2S probably reacts with organic substances to form sulphur-bearing compounds which in turn react with FeS to form FeS_2. Indeed these intermediate reactions may be part of the explanation of the heavy oil near the oil-water contact in fields where the reduction of sulphate is apparently taking place at present. Such reactions would also offer an explanation of the absence of free hydrogen in natural gas. If the sulphur was precipitated as native sulphur it would still not call for free hydrogen in natural gas since the hydrogen would be released in nascent form.

Assuming for the moment that the foregoing source of hydrogen is valid, the question arises as to whether the reactions are capable of furnishing an appreciable quantity of hydrogen. It has been suggested that hydrogenation may be the major part of the origin of petroleum if a source of sufficient hydrogen can be found.[6] If, however, we start with an "ancestral oil" such as suggested by Barton[7] not nearly so much hydrogen is necessary. Since any source capable of furnishing sufficient hydrogen for the conversion of organic matter to oil is obviously sufficient for hydrogenation of an ancestral oil, the writer has made a few preliminary calculations along the former line. Using Trask's[8] figures the writer has calculated the amount of hydrogen theoretically necessary to convert organic matter to oil in the Santa Fe Springs field in California. Estimating certain basic factors such as the average ultimate analyses of the oil and gas, and assuming that the depositional waters were of the same composition as ocean water, certain conclusions are possible. If the foregoing reactions are calcu-

[6] W. E. Pratt, "Hydrogenation and the Origin of Oil," *Problems of Petroleum Geology* (Amer. Assoc. Petrol. Geol., 1934), pp. 235–45.

[7] D. C. Barton, "Natural History of the Gulf Coast Crude Oil," *Problems of Petroleum Geology* (Amer. Assoc. Petrol. Geol., 1934), pp. 109–57.

[8] P. D. Trask, "Proportion of Organic Matter Converted to Oil in the Santa Fe Springs Field, California," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 20, No. 3 (March, 1936), pp. 245–69.

lated to yield the hydrogen necessary the following should be true in the field named.

(1) The sediments at the time of deposition contained 50 per cent ocean water.

(2) The sediment should contain about 0.3 per cent of $CaCO_3$ that was deposited after burial.

(3) The sediments should contain an average of about 0.33 per cent of FeS_2 that was formed after burial.

The figure given by Trask for the amount of oil generated is probably a maximum, and the other estimates by the author (except perhaps an assumed average chemical composition of connate water) were maximum figures so that the quantity of water in the sediments at the time of deposition is also a maximum figure. The writer can suggest reasons why the figures might be cut in half and still yield enough hydrogen.

Since the suggested source of hydrogen is derived by chemical reactions, the amount of hydrogen produced will be subject to the usual conditions of heat and pressure as modified by time. Hence these reactions would tend to give the results noted by Barton.[9] Since the amount and availability of iron will affect the completeness of desulphurization it is possible to account for some of the exceptions Barton noted. The ratio of the quantity of sulphate to the amount of organic matter of the proper kind would also be important in the degree of saturation and type of the oil.

Because the ratio of the quantity of sulphate to the quantity of source organic matter (not necessarily total organic content) governs the relative amount of hydrogen available, rich accumulations of organic matter might result in an unsaturated viscous oil. This could also be one reason why marine beds are necessary for the generation of large quantities of oil.

Most of the reaction must be postulated to have occurred in the source bed to permit the petroleum to migrate, but it could perhaps continue indefinitely or at least until all available sulphate was reduced.

In conclusion, the writer wishes it clearly understood that at present he is presenting the idea only as a hypothesis worthy of consideration. While no sound objection has been found to the foregoing reactions from a chemical, geological, or a quantitative standpoint, it is fully realized that there may be objections that have not yet become apparent.

In order that the foregoing figures may be revised and presented

[9] D. C. Barton, *op. cit.*

along with a full discussion of the subject, the writer will appreciate receiving estimates on the following.

(1) A weighted average ultimate analysis of the oil in the Santa Fe Springs field
(2) A weighted average ultimate analysis of the gas in the Santa Fe Springs field
(3) A weighted average analysis of the connate water in the Santa Fe Springs field
(4) The amount of gas generated for each barrel of oil in the Santa Fe Springs field

The writer would be glad to receive information as to the chemical composition of water associated with ocean muds.

Authentic cases of hydrogen in natural gas would also be appreciated.

OUR EXPERIENCE WITH THE UNDERGROUND STORAGE OF GAS (THE MANUFACTURERS LIGHT AND HEAT COMPANY, PITTSBURGH, PENNSYLVANIA)[1]

E. O. SCHILLHAHN[2]
Pittsburgh, Pennsylvania

In 1937 The Manufacturers Light and Heat Company established two storage fields in southwestern Pennsylvania for the underground storage of gas.

FIELD "A"

This field was developed primarily for the underground storage of artificial gas. The main producing sand is the Hundred-Foot sand of the Upper Devonian system. The wells average approximately 2,000 feet in depth and the sand averages approximately 10 feet in thickness. Most of the wells were drilled during the years 1900–1905 and the rock pressure prior to storage operations had declined from approximately 700 to 140 pounds.

Of a total of twenty-two wells in this field, twelve of them, located on approximately 1,300 acres, are used as storage wells. These twelve wells were reconditioned, tubed, and packed above the sand prior to storage operations.

Approximately three-quarters of a billion cubic feet of gas have been put into these wells with a total withdrawal of 15 per cent of the gas stored. While both artificial and natural gas have been stored, more than 85 per cent has been artificial gas. A study of the B.t.u. values indicates that the gas withdrawn to date has been artificial gas.

[1] Presented as part of a symposium at the production conference of the thirty-fifth annual Natural Gas Convention, Houston, Texas, May 6, 1940. This article is to be included in the Annual Proceedings of the Natural Gas Section of the American Gas Association (1940). Preprinted by permission.

[2] Geologist, The Manufacturers Light and Heat Company.

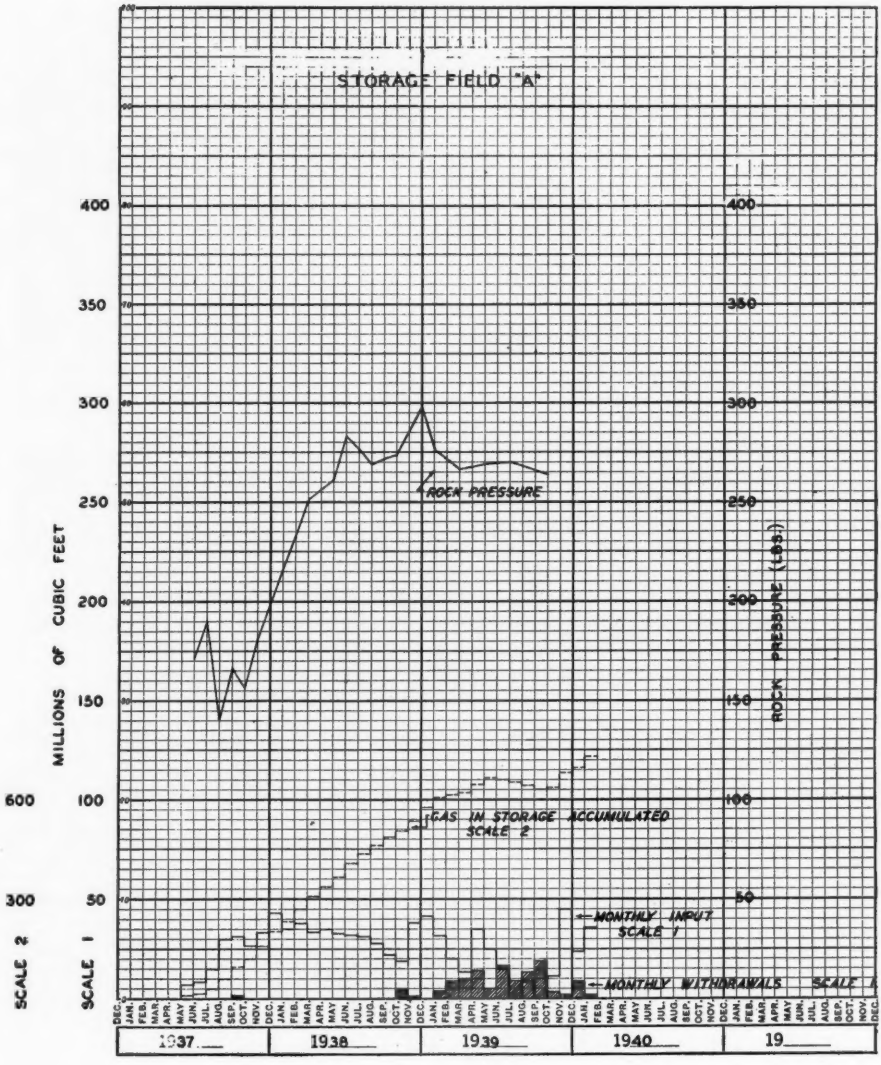

STORAGE FIELD "A"
ROCK PRESSURE
GAS IN STORAGE ACCUMULATED
SCALE 2
MONTHLY INPUT
SCALE 1
MONTHLY WITHDRAWALS
SCALE 1
MILLIONS OF CUBIC FEET
SCALE 2
SCALE 1
ROCK PRESSURE (LBS.)
600
300
400
350
300
250
200
150
100
50
1937
1938
1939
1940
19

FIG. 1

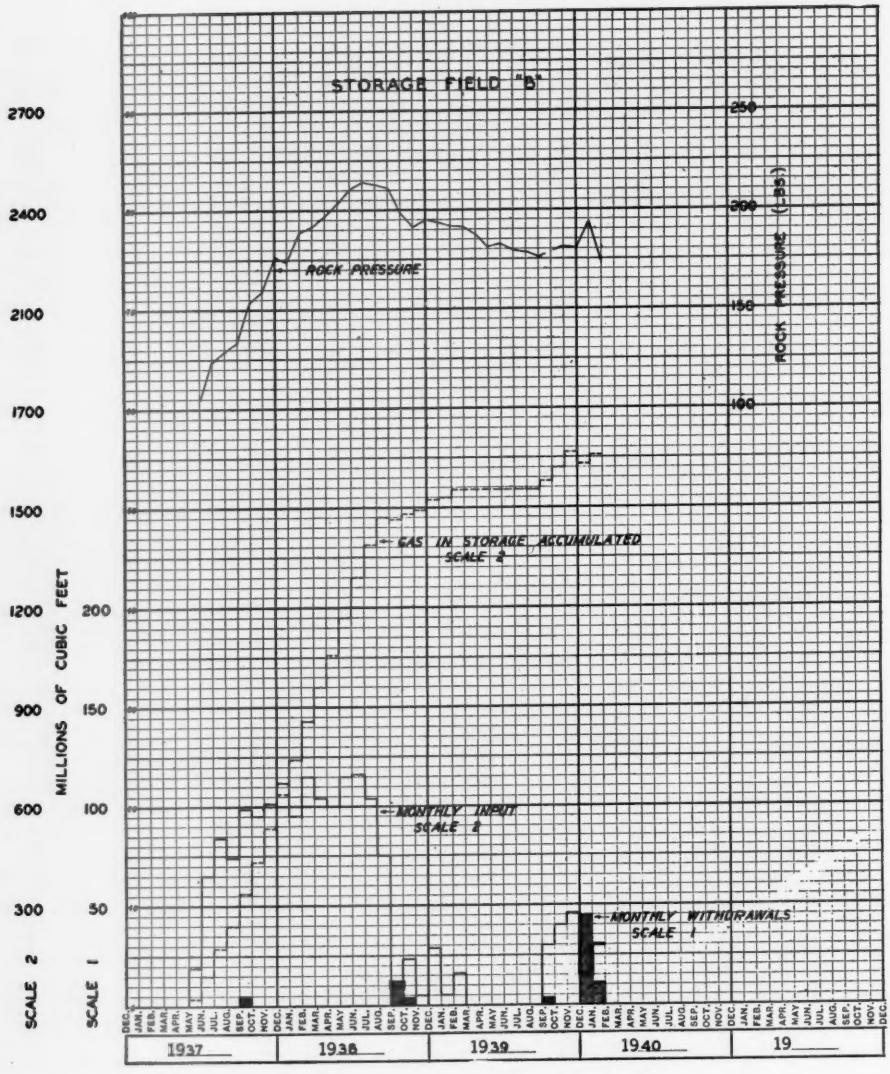

STORAGE FIELD "B"
ROCK PRESSURE
GAS IN STORAGE, ACCUMULATED SCALE 2
MONTHLY INPUT SCALE 2
MONTHLY WITHDRAWALS SCALE 1
ROCK PRESSURE (LBS.)
MILLIONS OF CUBIC FEET
SCALE 2
SCALE 1
2700
2400
2100
1700
1500
1200
900
600
300
200
150
100
50
250
200
150
100
1937
1938
1939
1940
19

FIG. 2

The average rock pressure of the storage wells since storage operations were begun has been increased from 140 to 260 pounds. The ten wells not used for storage surround the storage wells and are kept shut in for rock pressure study. To date no build-up in rock pressure on these outside wells has been recorded. The rock pressures of the twelve wells used for storage do not equalize even when the wells are shut in for extended periods.

Gas is stored into the wells from a compressor station with approximately 650 pounds discharge pressure and withdrawn at approximately 30 pounds pressure. At the present time the average daily delivery to storage will approximate $2\frac{1}{2}$ million cubic feet and the average daily withdrawals $1\frac{1}{2}$ million cubic feet.

The gas stored per pound increase in rock pressure is approximately $5\frac{1}{2}$ million cubic feet; per acre approximately 500,000 cubic feet and per well about 57 million cubic feet.

FIELD "B"

This field was established for the underground storage of natural gas. The main producing sands are the Salt, Big Injun, Fifty-Foot, Gordon, and Fifth sands and the wells have an average depth of 2,300 feet. These sands are not consistently productive in each well; in fact, no one sand is productive in all wells.

Most of the wells were drilled about the year 1900. The rock pressure prior to storage operations had declined from approximately 900 to 105 pounds. This field has 57 producing wells, 25 of which are grouped geographically and joined by pipe lines so as to make an operating unit. Of these 25 wells, 18 located on approximately 2,500 acres are used as storage wells. No reconditioning, other than bailing, was done on these wells prior to storage.

Approximately $1\frac{3}{4}$ billion cubic feet of gas has been put into these wells, with a total withdrawal of 5 per cent of the gas stored. Only natural gas has been put into this field.

The average rock pressure of the storage wells since storage operations were started has been increased from 105 to 175 pounds. The seven wells not used for storage are kept shut in for rock-pressure study. To date no build-up in rock pressure on these wells has been recorded. The rock pressures of the eighteen wells used for storage in this field do not equalize even when the wells are shut in for extended periods.

Gas is stored into these wells from a compressor station with approximately 250 pounds discharge pressure and withdrawn at approximately 10 pounds pressure. At the present time the average daily

delivery to storage will approximate 5 million cubic feet and the average daily withdrawal 6 million cubic feet. The gas stored per pound increase in rock pressure is approximately 21 million cubic feet; per acre approximately 660,000 cubic feet and per well about 92 million cubic feet.

GENERAL

In general, the storage operations in both fields are not at all continuous, being limited to periods when the operations are most suitable for either storing or withdrawing.

Both fields are operated as units in that all wells are used simultaneously for intake or withdrawal. The gas is measured at the compressor stations. Rock pressures are taken on storage and pressure wells at frequent intervals.

The failure of the rock pressures of the individual wells in both field "A" and field "B" to equalize, even when these wells are shut in for extended periods, tends to indicate that the gas put into the wells builds up cones of pressure near the base of the wells. This, apparently, is due to the low porosity and permeability of the sands.

The accompanying charts show graphically the storage and withdrawal periods and the accompanying rock-pressure fluctuations.

Although our experience has been limited, especially in relation to extended withdrawal periods, the value of these two underground storage fields in creating additional available gas for peak-load requirements seems well established. The fields are located along the main transmission lines and were used to good advantage this past winter.

As a result of our experience with the underground storage of gas, it is planned to establish in the near future additional small storage fields at available strategic points along our main transmission lines.

OUR EXPERIENCE WITH THE UNDERGROUND STORAGE OF GAS (THE PEOPLES NATURAL GAS COMPANY)[1]

F. H. FINN[2]
Pittsburgh, Pennsylvania

The underground storage of natural gas is not new to the industry. Successful storage experiments have been carried on in the states of

[1] Presented as part of a symposium at the production conference of the thirty-fifth annual Natural Gas Convention, Houston, Texas, May 6, 1940. This article is to be included in the Annual Proceedings of the Natural Gas Section of the American Gas Association (1940). Preprinted by permission.

[2] Geologist, The Peoples Natural Gas Company.

Oklahoma, Kentucky, Pennsylvania, and New York. Some of the projects date back as far as 1916. There have also been numerous experiments with natural-gas repressuring of oil fields, a procedure which in many respects is quite similar to that of natural-gas storage.

Injection of gas into depleted sands, as a means of relieving excessive pipe-line pressure, has been a common practice of many of the companies in the Appalachian area for years. However, these operations were not carried out in a systematic manner and can not be classed as gas storage. They did, however, demonstrate the feasibility of restoring gas to its natural reservoir.

The Peoples Natural Gas Company had used this method of relieving pipe-line pressures many years ago, particularly in their operations in Clarion County, and it was noted that the gas thus stored could be quickly recovered.

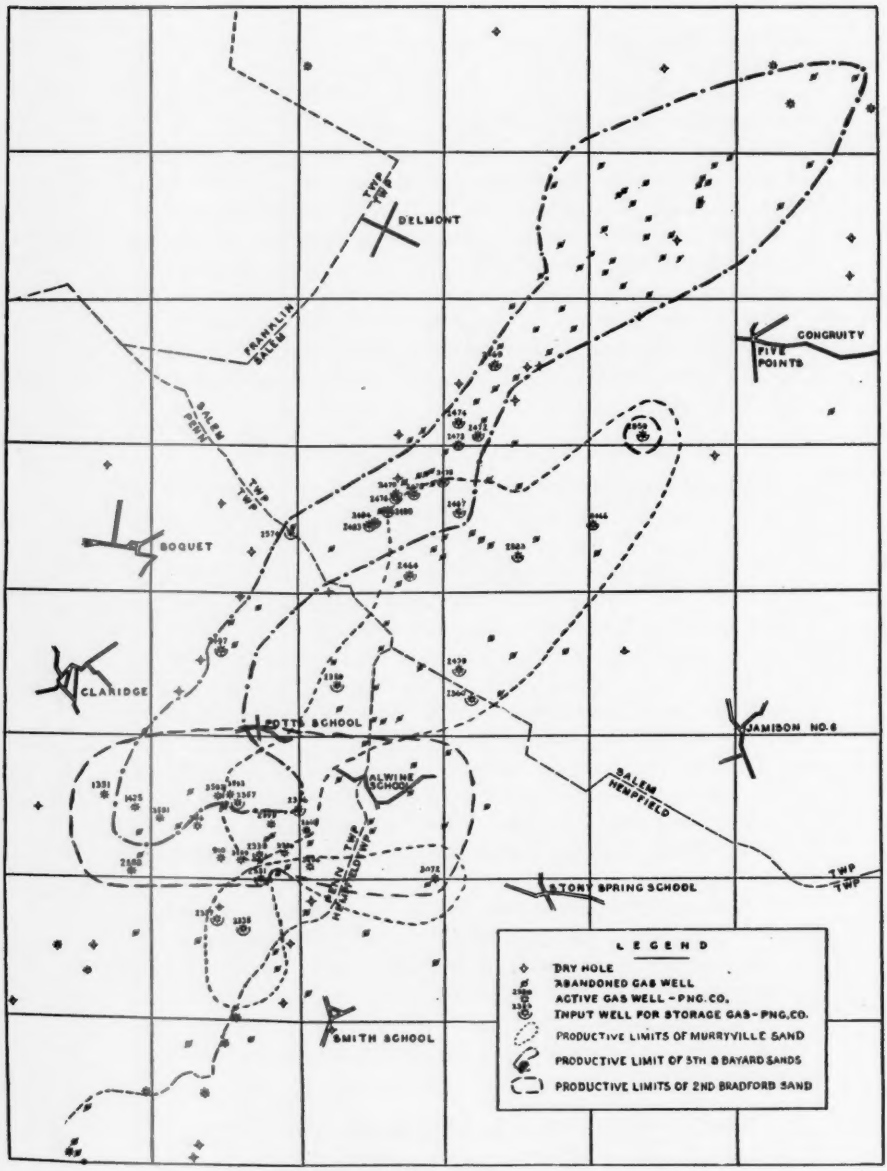
CAUSES CONTRIBUTING TO NEED FOR STORAGE

The major companies in the eastern gas-producing areas have resorted to underground storage in recent years as a means of meeting peak-load demands. Peak-load requirements are frequently four or five times greater than the average normal demand for gas. Most of the gas fields, from which the supply of gas for the Appalachian area is derived, are in a state of settled production and many are near depletion; consequently, the majority of the wells are relatively small and usually are producing at their capacity, even during times of normal demand in the winter months. When market demands are sharply increased during abnormally cold weather, it is no longer possible to open up a few large wells to meet these peak-load requirements. Reserves, however, are still adequate to supply the area for many years and storage of natural gas, during periods when market requirements are small, for use on days of peak-load demands, is obviously the solution to the problem.

Natural-gas storage reservoirs may be of two types: large pools in which considerable quantities of gas can be stored under relatively low pressure; and smaller pools for which less gas is required to build up to pressures which will insure a rapid daily rate of withdrawal at times when the gas is needed. For the particular needs in the Appalachian area, it is believed that the latter type of storage is much more efficient.

STORAGE EXPERIENCES OF PEOPLES NATURAL GAS COMPANY

Systematic storage of natural gas was first begun by the Peoples Natural Gas Company on May 1, 1937, in a nearly depleted pool



MAP 1.—Storage area, Salem, Penn, and Hempfield townships, Westmoreland County, Pennsylvania.

located in Salem, Penn, and Hempfield townships, Westmoreland County. The storage was begun in this area in order to conserve some of the large quantities of gas from the northern Oriskany gas fields which were highly competitive. On August 7, 1939, a small area near Murrysville was selected for underground storage, as it was strategically located near large centers of distribution and the gas could be quickly recovered on days of peak demand.

UNDERGROUND STORAGE—SALEM, PENN AND HEMPFIELD TOWNSHIPS, WESTMORELAND COUNTY

The area in which The Peoples Natural Gas Company first stored gas is located in the aforenamed townships and is a rather extensive pool. The area which was affected by this storage embraces approximately 5,500 acres. However, the gas injected was stored principally in the Murrysville sand; hence, the area of effective storage is considerably less than the foregoing, or about 2,780 acres. In selecting this area for storage, it was first necessary to determine by means of a careful geological study, whether or not the gas could be retained in the portion controlled by the company. This was accomplished by studying the records of all the wells which had been drilled in the area and determining the limits of effective drainage in the various producing sands. The principal sands in this pool are the Murrysville, Fifth and Bradford, the depths of which are 1,400, 2,000, and 3,300 feet, respectively. The production from the Bradford sand is very small, and as the rock pressure in this formation was approximately 400 pounds, no storage took place in this sand. The rock pressure of the Fifth sand was approximately 35 pounds in most of the area at the time storage started; consequently, this formation did not take much of the gas which was injected, except in some portions of the field where it had been more completely drained prior to storage. The Murrysville sand was consequently the principal sand in which storage took place. This sand is more porous than most of the sands in the Appalachian area, with porosity ranging as high as 25 per cent. The map shows the location and drainage area of the principal sands involved in storage (Map 1).

This gas pool is located on a dome on what is known as the Grapeville anticline. The gas is accumulated in lenses of varying porosities in the different sands; hence, the accumulation is controlled by both structure and stratigraphic trapping. The original open flow of wells in this area is not well known, as many of them were drilled 40 years ago and records were not kept. However, it is believed that the Murrysville wells averaged about 3 million cubic feet of gas per day.

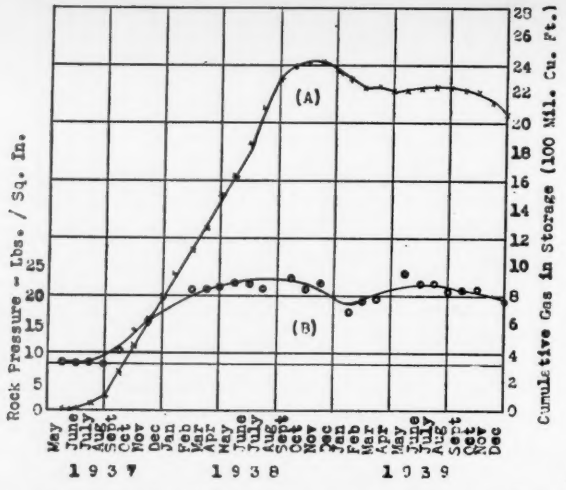


FIG. 1.—Curves showing: (A) amount of gas in storage *versus* time; (B) rock pressure *versus* time, Salem, Penn, and Hempfield townships, Westmoreland County, Pennsylvania.

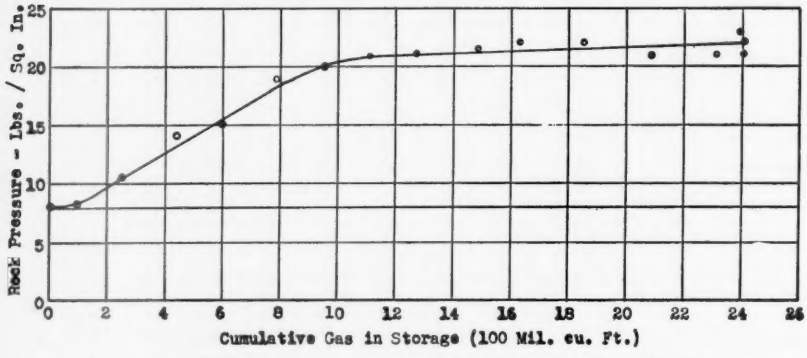
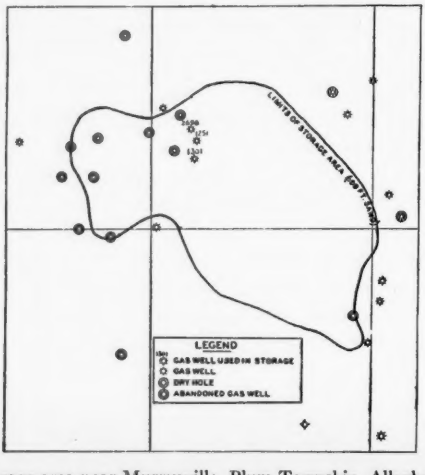


FIG. 2.—Curve showing relationship between rock pressure and amount of gas in storage, Salem, Penn, and Hempfield townships, Westmoreland County, Pennsylvania.



MAP 2.—Storage area near Murrysville, Plum Township, Allegheny County, Pennsylvania. Scale: 1 inch = 3,960 feet.

The wells were all checked to see that they were not leaking or in a state of disrepair, but other than this, nothing was done in the way of installing new equipment. This made it possible to use this storage area with very little initial expense to the company. Annual gas-well royalties averaging about $75 per year had been paid to the lessors in the area, and these rentals were continued for use of the wells for storage purposes. In a few cases, strategic properties, on which wells had not been drilled, were held by means of the usual annual acreage rental.

The company had two pump stations in the area which were capable of handling the gas for storage. Connections were changed to make it possible to inject gas or withdraw it as conditions demanded.

There were thirty-one wells being served by the field lines which carried the gas from the pumps to storage. However, only twenty-seven of these wells acted as effective intakes. These are designated by a symbol on Map 1.

The rock pressure at the time storage was begun in this area, May 1, 1937, was about 8 pounds (well-head pressure). Gas was injected into the area over a period of 26 months at rates which varied according to the availability of gas for storage. The highest daily rate of storage was about 9 million cubic feet per day. This was accomplished by means of line pressures of about 58 pounds, or a difference of 36 pounds between line pressure and rock pressure, the rock pressure having built up to 22 pounds at the time this amount of gas was injected.

Approximately 87 million cubic feet of gas were required per pound of build-up in rock pressure in the early stages of storage. However, about 174 million cubic feet of gas per pound or rock pressure build-up were required to accumulate the maximum amount of gas in storage. Figure 2, which shows "Rock Pressure *vs.* Accumulated Gas in Storage," reveals that the rock pressure build-up was not exactly a straight line. This is probably due to the fact that the gas did not immediately settle out to all portions of the pool. It is also probable that storage in the Fifth sand did not take place until the rock pressure had built up to about twenty pounds in the Murrysville sand. After a maximum gas storage of 2,434 million cubic feet, the rock pressure of the Murrysville sand was found to have built up from 8 pounds to 22 pounds.

The two curves shown in Figure 1 demonstrate the rock-pressure build-up, and the cumulative gas in storage, both plotted against time. It will be noted that these curves are very similar.

WITHDRAWALS FROM STORAGE

Since this pool was very large, the increased rock pressure accomplished by maximum storage was relatively small, that is, 14 pounds. The differential between rock pressure and line pressure was necessarily considerably smaller in withdrawal operations than it had been possible to obtain while injecting gas; consequently maximum recovery per day was smaller than the maximum daily rate of intake. The largest daily withdrawal from the pool has been approximately 4 million, which was accomplished by means of a line pressure of 14 pounds, at a time when the rock pressure in the Murrysville sand was 20 pounds, or with a differential of 6 pounds. Because of the relatively low rock pressure, it was usually necessary to pump the gas out of the pool in order to transport it through the company's pipe lines. Thus, a pumping operation was necessary both on intake and withdrawal from storage.

CONCLUSIONS AND RESULTS

The area in Salem, Penn, and Hempfield townships proved well adapted to a large storage of natural gas. It demonstrated that a large amount of gas could be safely stored in this area, as the gas was definitely confined within the area controlled by the company without any loss during storage. The size of the pool, however, proved to be a disadvantage, in that it required a very large storage before any great increase in the daily capacity to produce for the wells could be accomplished, as the rock pressure factor, which is so important in capacity to produce, was not greatly increased. Although the storage did not help greatly for peak loads, the experiment is considered to have been successful in that it conserved for the consumer, a large amount of gas which would otherwise not have been available at a time when it was needed and this was accomplished without the necessity of installing expensive equipment.

UNDERGROUND STORAGE IN AREA NEAR MURRYSVILLE

In 1939, some of the sources of supply, which made possible a large daily capacity to produce, were curtailed, and the company made a study of its properties to see if a small storage pool was available from which a relatively large capacity to produce over a limited time could be obtained. A small area of this type was found to be available near Murrysville. The map shows the size and extent of this storage area (Map 2).

The pool selected had three wells drilled to the 100-foot sand, all of which had very large open flows at the time they were drilled. There

had been sufficient drilling in the area to definitely define the limits of this pool. The pool is the result of stratigraphic trapping on the north flank of the Murrysville anticline, and represents a small area of very porous 100-foot sand. The sand in this area probably has a porosity of at least 25 per cent as it is a conglomerate rather than a true sand. The average depth of the wells is 1,870 feet and the thickness of the pay is 10 feet. The sand thickness is much greater, being 120 feet. The attached table is a summary of the wells used for storage in this area. The pool includes a maximum drainage area of 630 acres and may possibly be considerably smaller in extent than is indicated on the map. The three wells used for storage in this pool were cleaned out and generally reconditioned in the summer of 1939, and storage was started on August 7, 1939. The area was strategically located at a point on the company's pipe line where gas could be injected with a line pressure of 250 pounds, without any additional expense for construction of pump stations, other than the pumping facilities which were already available. When storage was begun in this area, the rock pressure (well-head pressure) was 28 pounds. Gas was injected into the sand at a daily rate varying from 1,400,000 cubic feet to 3,200,000 cubic feet, the rate being determined by the amount of gas available without inconvenience to the company on those days when storage took place. However, it was found that the maximum rate of input for the three wells combined was approximately 3,200,000 cubic feet per day. The differential between line pressure and rock pressure required to store approximately 3 million cubic feet of gas daily varied from eight pounds to 47 pounds. This indicated that the wells had a limited capacity of intake, as the differential above 10 pounds seemed to make little difference in the amount of gas stored. However, exact data on this condition were not available at the time this report was written.

The response on rock-pressure build-up from the effect of accumulated storage was immediate in this small area, and demonstrated the advantage of having a single horizon of limited extent in which to inject the gas. It was found that the rock pressure of the pool was increased one pound for every 1,500,000 cubic feet of gas injected. With a maximum gas storage of 252 million cubic feet, the rock pressure had increased from 28 pounds to 196 pounds. The curve shown in Figure 3 indicates the rock-pressure build-up *vs.* cumulative gas in storage. It will be noted that the curve is a straight line similar to that displayed by most gas pools as they are depleted. The curves in Figure 4 and Figure 5 represent rock-pressure build-up *vs.* time, and cumulative gas in storage *vs.* time, respectively. The shapes of the

curves are similar to each other as was the case with the Salem storage area hereinbefore described. A table showing the amount of gas

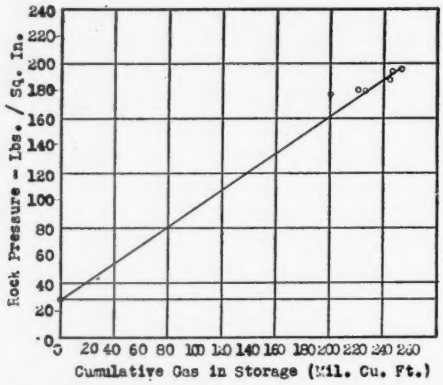


Fig. 3: Curve Showing Relationship Between Rock Pressure and Amount of Gas in Storage

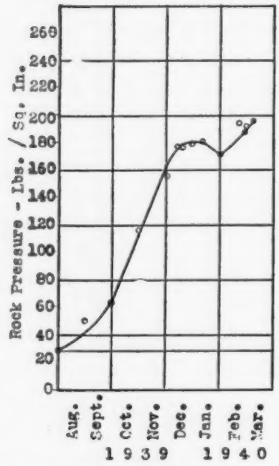


Fig. 4: Curve Showing Rock Pressure Vs. Time

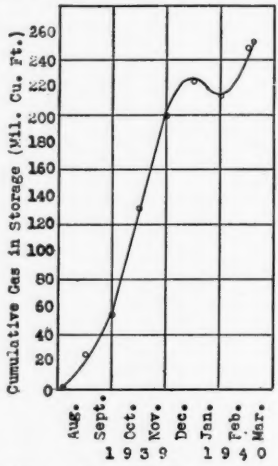


Fig. 5: Curve Showing Amount of Gas in Storage Vs. Time

FIGS. 3, 4, and 5.—Curves relating to storage of gas near Murrysville, Plum Township, Allegheny County, Pennsylvania.

stored and withdrawn, and cumulative in storage by months for this pool is also shown.

WITHDRAWALS FROM STORAGE

Withdrawals from storage in this pool were made during the months of January and February, 1940, on days when market requirements were so severe that this gas was essential to supply the company's consumers. The highest daily rate of withdrawal was 4,500,000 cubic feet per 24 hours (calculated) which is considerably higher than the highest daily rate of storage which had been accomplished.[3] The rock pressure of the pool was 176 pounds (estimated) at this time and the line pressure which this gas fed against was 165 pounds (estimated), or a differential of 11 pounds.

It was not necessary to pump the gas out of this pool because of the relatively high build-up in rock pressure which had taken place. The loss in rock pressure occasioned by withdrawals from storage was approximately the same as that accomplished in the reverse during input operations.

CONCLUSIONS AND RESULTS

The small area near Murrysville demonstrated to the company the advantage of a small storage reservoir, as it required a much smaller storage to build up pressures which would accomplish a large capacity of daily delivery from the wells. This pool will probably be equipped to store gas up to pressures of 500 pounds during the coming year, and it is believed that it will produce well in excess of twenty million per day if this is done. Back pressure tests are now being made to determine the capacity of the wells under various rock pressure conditions.

In order to build the rock pressure up to 500 pounds, it will, of course, be necessary to pump the gas in; however, it will feed out naturally against the prevailing line pressure in the immediate area. The pool also is very close to Pittsburgh, one of the large markets served by The Peoples Natural Gas Company; hence, the effect of any gas withdrawn from this storage is immediate.

To date, very little expense has been necessitated in the preparation of this area for storage. The major expense has been the reconditioning of the wells and the installation of a metering station. This will probably be augmented by a small pump station in the near future.

It is believed that small storage areas of this type are ideal to

[3] Subsequent to the writing of this report, gas was withdrawn from this pool on March 26, 1940, at which time the rock pressure had settled to 193 pounds. The wells produced for 5 hours at a rate equivalent to 8.5 million per 24 hours. A back pressure of 160 pounds was held on the wells at this time.

STORAGE DATA—SALEM, HEMPFIELD & PENN TOWNSHIPS, WESTMORELAND COUNTY, PENNA.

TABLE A
EXAMPLES OF DAILY RATES OF INTAKE

Date	Amount M.C.F.	Sta. Pr.	Line Pr.	Rock Pr.	Sta. Pr. -R.P.	L.P. -R.P.
9/20/37	5,343	51	30	10½	40	20
10/27/37	6,681	54	30	14	40	16
4/25/38	8,889	77	57	21½	55	35
4/28/38	8,569	79	58	21½	58	37
7/28/38	7,276	70	55	21	50	34
8/25/38	6,516	65	48	21	43	21
10/24/38	665	24	23	21	3	2
5/26/39	464	24	25½	23½	½	2

TABLE B
EXAMPLES OF DAILY RATES OF WITHDRAWAL

11/24/39	3,653	4	14	20	16*	6†
11/29/39	2,069	7	17	20	13*	3†
12/28/39	3,480	5	17	19	14*	2†
12/29/39	3,217	4	17	19	15*	2†

(* –R.P.–Sta. Pr.) († –R.P.–L.P.)

TABLE C
DATA ON TOTAL CUMULATIVE GAS STORED AND WITHDRAWN

Date	Cumulative Gas M. C. F. Stored	Withdrawn	In Storage	Avg. R.P. Murr. Sd. Wls.
6/30/37	26,519	0	26,519	8
12/31/37	806,396	0	806,396	19
12/31/38	2,435,891	51,685	2,384,206	20
6/30/38	1,868,229	2,503	1,865,726	22
6/30/39	2,550,745	265,550	2,285,195	22
12/31/39	2,574,833	442,151	2,132,682	19
Total 12/31/39	2,574,833	442,151	2,132,682	

STORAGE DATA—MURRYSVILLE AREA—PLUM TOWNSHIP, ALLEGHENY COUNTY, PENNA.

TABLE D
DATA ON STORAGE WELLS

Well No.	Sands	Original Conditions Open Flow	Date	R.P.	Open Flow After Reconditioning 1939	Rock Pressure Data Before Storage 6/26/39 Lbs.	During Storage Operation 12/12 1939 Lbs.	1/10 1940 Lbs.	2/21 1940 Lbs.	2/28 1940 Lbs.	3/6 1940 Lbs.
1251	100′	11,700M	1916	300 lbs.	1,120M	28	178	182	195	188	196
1301	100′	3,900M	1917	—	1,118M	28	178	182	195	188	196
2698	100′	7,700M	1916	—	419M	28	178	182	195	188	196

TABLE E
EXAMPLES OF DAILY RATES OF INTAKE

Date	Amount M.C.F.	Sta. Pr.	R.P. (Calc.)	Sta. Pr. -R.P.
8/ 8/39	1,563	51	29½	21½
8/17/39	2,018	76	39	37
10/ 3/39	2,487	97	70	27
10/ 6/39	3,000	110	73½	36½
10/31/39	3,165	175	122½	52½
11/ 1/39	3,029	176	125	51
11/13/39	3,020	185	145½	39½
11/21/39	3,013	194	161½	32½
11/23/39	3,213	198	166½	31½
12/22/39	2,583	188	177½	10½

TABLE F
EXAMPLES OF DAILY RATES OF WITHDRAWAL

1/ 3/40	4,511†	30	176	146*
1/19/40	3,726†	30	174	144*
1/29/40	4,416†	31	168	137*

(†-Calculated) (* Rock Pr.—Station Pressure)

TABLE G
DATA ON TOTAL CUMULATIVE GAS STORED AND WITHDRAWN

Date	Cumulative Gas M. C. F. Stored	Withdrawn	In Storage
8/31/39	35,761	0	35,761
9/30/39	54,269	0	54,269
10/31/39	131,303	0	131,303
11/30/39	201,153	870	200,283
12/31/39	226,351	870	225,481
1/31/40	226,351	12,088	214,263
2/29/40	258,174	13,184	244,990
3/ 6/40	264,760	13,184	251,576

meet the abnormal peak load requirements of the major distributing companies in the Appalachian area.

UNDERGROUND STORAGE—FARMINGTON FIELD—TIOGA COUNTY, PENNSYLVANIA

In addition to the storage projects which have been conducted by The Peoples Natural Gas Company, and which have been described here, the writer is familiar with another storage project which took place in the Farmington field, Tioga County, Pennsylvania. This project was conducted jointly by the New York State Natural Gas Corporation and the North Penn Gas Company. The experiment worked out very successfully and demonstrated that it was practical to store gas in a structurally controlled pool in the Oriskany sandstone.

Vice-president and general manager Isherwood, of the North Penn Gas Company, has described this experiment in a report to be given at this meeting for the American Gas Association.

GENERAL CONCLUSIONS AND RESULTS OF STORAGE BY PEOPLES NATURAL GAS COMPANY AND NEW YORK STATE NATURAL GAS CORPORATION

As a result of the experience of The Peoples Natural Gas Company and the New York State Natural Gas Corporation, it has been found that the most effective storage for all practical purposes, is in small pools where large open-flow wells are available, thus resulting in high capacity to produce for a relatively small amount of gas stored. It is also considered important that the storage take place under conditions whereby the gas is pumped only one way, that is, either pumped into storage or pumped out of storage. Pumping of the gas both ways increases the expense considerably.

Storage has been found to be an excellent solution for the problem of peak loads, as the storage process can be accomplished at times when gas is not needed so badly for the markets, and withdrawal can be made at a rapid rate when market requirements are excessive.

It may readily be seen that storage may be used as a stabilizer by permitting production from the active wells at a steady rate throughout the year, putting the gas in storage in summer and withdrawing the same gas in the winter when it is needed.

It is also important to consider the ability to withdraw the gas rapidly from storage in any undertaking of this type, as it is not economical to tie up large quantities of gas over a long period of time, since the interest on the value of the gas will over-balance the profit derived from the sale when the gas is needed.

It is believed that the most economical type of storage is that

which can be made in pools which will hold from 500 million to 3 billion cubic feet of gas at a rock pressure of not more than 500 pounds, and from which the gas can be withdrawn at a rate which will accomplish complete emptying of the storage in 6 months time if it is needed.

DISCOVERY OF OIL IN ELLENBURGER FORMATION, K.M.A. OIL FIELD, WICHITA COUNTY, TEXAS[1]

VERNON E. AUTRY[2]
Wichita Falls, Texas

The Fain-McGaha Oil Corporation of Wichita Falls, Texas, completed its Griffin well "B" No. 16 on April 7, 1940, at the depth of 4,372–4,389 feet, producing initially 800 barrels of oil per day, the flow being on 1-inch choke through tubing. The pay formation was dolomitic limestone of Ellenburger age. The gravity of the oil is 41.8°. The depth to the top of the Ellenburger was 4,315 feet. Several wells in the K.M.A. field had previously been drilled through the regular producing formation at 3,750 feet only to find the Ellenburger nonproductive.

The discovery well is favorably located structurally, being only a few feet downdip from the top of the structure.

It was the intention of the operators to drill through the regular K.M.A. sand which produces from 3,750 to 3,825 feet, and drill down to the Ellenburger formation. With this in mind, a 9¼-inch hole was drilled all the way.

A showing of oil was encountered in the top of the Ellenburger at 4,315–4,332 feet, but it was not tested. The second showing in the dolomite came in at 4,372–4,389 feet. Drilling continued in limestone and dolomitic limestone, without showings of oil or gas, to the depth of 4,486 feet. A drill-stem test was then run, with big-hole packer set at 4,352 feet, and with tool open 20 minutes, the well showed 650 feet of oil and oil-cut mud with a bottom-hole pressure of 1,400 pounds. Seven-inch casing was then run and cemented with 400 sacks at 4,352 feet.

The only development since this discovery is the completion of the Magnolia Petroleum Company's Thom No. 3. This well is located about 1¾ miles southeast of the discovery well and is a regular K.M.A. sand producer at 3,850 feet. It was deepened to the Ellenburger and was completed, May 30, producing 60 barrels of oil and

[1] Manuscript received, June 25, 1940.

[2] Geologist, Fain-McGaha Oil Corporation.

60 barrels of water per day. The pay zone extends from 4,415 to 4,423 feet. The top of the Ellenburger was found at 4,414 feet. This well showed the structure to be 85 feet lower than that in the discovery well.

The importance of the discovery remains unknown, but a few hundred acres on top or near the top of the structure have a good chance of producing.

HENDERSON POOL DISCOVERY, CLAY COUNTY, TEXAS[1]

GEORGE P. HARDISON[2]
Tulsa, Oklahoma

The Shell Oil Company's Henderson No. 1, discovery well of the Henderson pool, is located 1,295 feet from the west line and 990 feet from the north line of Section 2605, T.E. & L. Survey, southwestern Clay County, Texas.

The well was plugged back from a total depth of 3,824 feet to 3,545 feet, and was completed on March 2, 1940, after pumping 287.4 barrels of 38° gravity oil in 24 hours. The producing sand, upper Strawn in age, occurs from 3,504 to 3,523 feet. Other sands which appear to have commercial possibilities, were present at 3,154–3,207 feet, 3,419–3,439 feet, and 3,556–3,580 feet.

The structure was found by means of seismograph exploration.

Prior to the drilling of Henderson No. 1, a few shallow tests and one deep test (dry hole) had been drilled in the vicinity. Henderson No. 2, located 990 feet south of the discovery well, has been successfully completed in a lower "pay" at 3,538–3,551 feet, with an initial flowing production of 238 barrels in 24 hours.

[1] Manuscript received, June 25, 1940.

[2] Geologist, Shell Oil Company, Inc.

LOG OF WILDCAT WELL, UNION COUNTY, IOWA[1]

W. E. McHUGH[2]
Wichita, Kansas

The log of a wildcat well drilled recently in Union County, Iowa, in the northeastern part of the Forest City basin, should be of interest on account of the stratigraphic information and data on formation waters which it reveals. This test, the Phillips Petroleum Company's Creston No. 1, in the center of the SE. $\frac{1}{4}$, NE. $\frac{1}{4}$ of Sec. 31, T. 71 N.,

[1] Manuscript received, July 5, 1940.

[2] Geologist, Shell Oil Company, Inc.

R. 30 W., was drilled with cable tools. It was spudded, November 28, 1939, and completed, April 1, 1940. The location was made on a structure discovered by seismograph-exploration work. The well was abandoned in the Willow River formation of the Prairie du Chien group of the Ordovician system. No showings of oil or gas were found. The elevation of the derrick floor is 1,211 feet above sea-level.

The following description of the formations is based on a microscopic examination of the well cuttings by the writer. Acknowledgment is made to H. G. Hershey, assistant State geologist of Iowa, for his helpful suggestions and information on recent correlations by the Iowa State Geological Survey.

Age of Rock	*Depth in Feet*	*Description*
Quaternary		
Pleistocene	305	Glacial drift of Nebraskan and Kansan age (20-inch casing set at 100 feet)
Pennsylvanian		
Missouri		
Lansing, Kansas City, Bronson	580	Alternating limestones and shales, predominantly limestones. Very thin coal bed at 545 feet. 15-inch casing set at 400 feet
Des Moines		
Pleasanton and Henrietta	765	Predominantly shale with few thin limestone beds. Fort Scott limestone at 755–765, yielding 2 barrels of salt water per hour. Coal bed at 710 feet
Cherokee	1,055	Dark shale with several coal seams. A few thin limestones
	1,175	Sand—some shale near top. Hole full brackish water at 1,055–1,125
	1,177	Detrital sand and chert
Mississippian		
Meramec		
Ste. Genevieve	1,225	Alternating dark brown limestone and sand
St. Louis	1,253	Buff, fine-grained dolomitic limestone with small amount of chert
Warsaw	1,298	Sugary, dolomitic limestone, cherty at top and base. 6 bailers fresh water per hour, 1,277–1,290 feet
	1,303	Gray shale
Osage		
Keokuk and Burlington	1,486	Very cherty limestone and dolomitic limestone. Increase in water (fresh), 1,377–1,380. Hole full of fresh water, 1,442–1,448 feet
Kinderhook		
Hampton	1,492	Gray-green shale
	1,545	Gray, finely crystalline limestone, cherty at top
Maple Mill	1,560	Brick-red shale. Thin dolomite bed near base
	1,595	Gray-green shale
Devonian		
Cedar Valley	1,720	Brown, finely crystalline limestone. Ran 10-inch casing, 1,680. Hole full fresh water, 1,690–1,701 feet
	1,840	Alternating brown, finely crystalline dolomite and limestone, few slightly sandy zones. Hole full fresh water, 1,808–1,820 feet
	1,920	Brown to buff, medium to finely crystalline dolomite. Hole full fresh water, 1,850–1,853 feet

Age of Rock	Depth in Feet	Description
	1,946	Buff, finely crystalline to sucrose dolomite, some gypsum
	1,947	Rounded sand
Wapsipinicon	1,970	Buff, coarsely crystalline dolomite, some gypsum at top
	2,000	Brown, finely crystalline dolomite
	2,110	Buff, finely medium crystalline dolomite—much gypsum, few limestone streaks
	2,255	Drilled up very fine, flour-like, white, gypsum and dolomite
	2,275	Light brown, medium crystalline dolomite and rounded sand
	2,277	Gray and green sandy shale
Silurian	2,298	Gray, coarse to medium crystalline dolomite
Ordovician		
Maquoketa	2,312	Light green shale
	2,330	Brown, fine to medium crystalline dolomite with some sand
	2,336	Green and red shale
	2,346	Pale green shale—much pyrite
Galena	2,448	Buff to drab, medium to fine, crystalline dolomite, some white chert. 8-inch casing set at 2,368 feet
	2,478	Drab, coarsely crystalline dolomite (Fernvale type), much white and gray chert at base
	2,580	White, gray, brown chert, some brown medium crystalline dolomite. Hole full fresh water, 2,450–2,459 feet
	2,704	Brown, medium crystalline dolomite, slightly cherty
	2,723	Medium crystalline sandy dolomite
Decorah	2,728	Shale and argillaceous dolomite with some carbonaceous matter
Platteville	2,755	Brown, finely crystalline dolomite, sandy
Glenwood	2,759	Dark green shale
St. Peter	2,789	Sand, medium grain, well rounded at top, angular at base, pyritic. Fresh water, 2,763–2,782. Cable-tool cores, 2,761–2,762. Cable-tool cores, 2,782–2,786 feet
Prairie du Chien		
Willow River	2,860	Brown to drab, coarse to finely crystalline dolomite, few thin streaks of sand, chert, and green shale. Porous streaks containing fresh water, 2,800–2,860. Cable-tool cores were taken from 2,791 to 2,860 feet, total depth

WATER ANALYSES FROM ALL FORMATIONS IN PHILLIPS PETROLEUM COMPANY'S CRESTON NO. 1
(Parts per Million)

Depth in Feet		Formation	Total Solids	Na & K	Ca	Mg	Cl	HCO_3	SO_4	CO_3	Note
From	To										
755	765	Ft. Scott	7,619	2,727	34	32	3,307	530	953	36	
1,050	1,135	Cherokee sand	6,085	2,071	34	29	2,030	703	1,209		
1,277	1,290	Warsaw	4,253	1,330	39	17	594	591	1,644	29	
1,377	1,380	Osage	4,834	1,447	84	35	674	619	1,975		Hydrogen sulphide odor
1,442	1,448	Osage	4,255	1,008	226	73	246	451	2,251		
1,690	1,701	Cedar Valley	4,651	935	372	110	388	369	2,477		
1,808	1,820	Cedar Valley	4,164	542	446	204	273	272	2,427		
1,850	1,853	Cedar Valley	4,113	505	512	169	250	295	2,382		
2,450	2,459	Galena	2,694	397	275	127	406	218	1,271		
2,763	2,782	St. Peter	2,525	418	227	116	452	222	1,090		
2,800	2,860	Willow River	2,105	343	206	87	379	222	868		

These analyses were made by H. L. Hibbard of the Phillips Petroleum Company, Research Laboratory. Bartlesville, Oklahoma.

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REVIEWS AND NEW PUBLICATIONS

* Subjects indicated by asterisk are in the Association library and available, on loan, to members and associates.

FORAMINIFERA, THEIR CLASSIFICATION AND ECONOMIC USE, BY JOSEPH A. CUSHMAN

REVIEW BY BYRON N. COOPER[1]
Wichita, Kansas

Foraminifera, Their Classification and Economic Use, by Joseph A. Cushman. Third edition (1940). 535 pp., 69 pls. Cloth. Price, $6.00. Harvard University Press, Cambridge, Massachusetts.

The third edition of Cushman's manual is a substantial improvement over the two previous editions.

Nearly 500 genera, comprising 49 families, are described and are, for the most part, illustrated in a very suitable manner. Among the many distinctive contributions of this edition are new descriptions of the Fusulinidae, by Carl O. Dunbar, and of the Orbitoididae, by T. Wayland Vaughan and W. Storrs Cole. Key plates, separately bound in the second edition (1933), have been added to, and have been bound with the text. The key to genera and families has been improved and somewhat expanded. An excellent bibliography of approximately 1,000 papers on the Foraminifera is organized according to subject matter and to the geographic occurrence and geologic age of the forms and faunas described.

The introductory chapters are essentially the same as those of the second edition, although some have new chapter headings. Although they are better illustrated than the corresponding chapters of Galloway's manual, these chapters are poorly written. Too many subjects are omitted entirely. The fine points of taxonomy of the Foraminifera would never be learned by reading these chapters. In spite of this serious defect, this edition will find a warm welcome from micropaleontologists.

[1] University of Wichita. Manuscript received, May, 1940.

A HANDBOOK OF ROCKS, BY J. F. KEMP

REVIEW BY W. C. KRUMBEIN[1]
Chicago, Illinois

A Handbook of Rocks, by J. F. Kemp. Revised and edited by F. F. Grout. Sixth edition (1940). 300 pp., illustrated. D. Van Nostrand Company, New York. Price, $3.00.

The sixth edition of this widely used book carries on the tradition of earlier editions in its clarity of presentation and in the wise selection of topics. Professor Grout has retained much of the earlier organization of the book,

[1] Department of geology, University of Chicago. Manuscript received, June 7, 1940.

but has completely rewritten all of the chapters, and redistributed the emphasis in terms of modern developments in petrology. Petroleum geologists will perhaps be most interested in the treatment of sedimentary rocks, which occupies nearly a third of the volume. Included in this section are discussions of the processes of weathering, transportation, and deposition, as well as the products of such processes. Classification and description of sedimentary rocks receives much of the space, but the topics of correlation and the examination of well cuttings are also discussed.

In general plan the volume begins with the igneous rocks, classified into clans. Along with the descriptive portions are discussions of the petrological aspects of the rocks; the section closes with general remarks on the igneous rocks, including chemical composition, structures, textures, and the like.

The sedimentary section follows the igneous section. The third part of the book concerns metamorphism and metamorphic rocks. Both regional and contact varieties are discussed. As in previous sections, the closing summary unifies and integrates the material. A closing section of 45 pages is devoted to rock calculations (including chemical composition, size-analysis diagrams, *et cetera*) and to sample descriptions of rocks. This portion offers numerous suggestions for problems which are helpful to instructors using the book.

From a teaching point of view the book is particularly well adapted to introductory courses inasmuch as it is based on megascopic methods entirely, and does not require the use of a petrographic microscope. This very feature renders the book also useful to geologists who rely on binocular microscopes for the examination of rock cuttings, inasmuch as the descriptive features are based on readily observable characteristics. The new edition will thus prove highly useful both to teachers and to geologists whose work involves the rapid examination, classification, and interpretation of rock data.

DICTIONARY OF GEOLOGICAL TERMS, BY C. M. RICE

REVIEW BY JOHN T. ROUSE[1]
Tyler, Texas

Dictionary of Geological Terms, by C. M. Rice, Edwards Brothers, Inc., Ann Arbor, Michigan (1940). 461 pp. Price, $6.00. Address Miss C. M. Rice, 14 Vandeventer Ave., Princeton, New Jersey.

In this dictionary Miss Rice has made a most comprehensive compilation of approximately 17,000 geological terms, exclusive of stratigraphic formations and paleontological genera and species. As stated in the preface, the aim of the author "has been to bring together in one convenient volume the definitions of terms in use in the various branches of Geology."

Miss Rice was secretary to the department of geology of Princeton University for nearly 20 years and took advantage of her position to assemble these geological terms. All of the definitions have been taken from reliable, published works. Following each definition the source is given so that the reader will know where to look for additional information if desired. In the case of those definitions taken from standard works, such as *Glossary of the Mining and Mineral Industry* and *The Nomenclature of Petrology*, it will be

[1] Magnolia Petroleum Company. Manuscript received, June 19, 1940.

necessary to look in these previously published definitions in order to find reference to the original source and discussion of the term. The geologic profession is indebted to Miss Rice for assembling all of our geological definitions in one volume so that it is no longer necessary to hunt terms in different volumes by different authors.

In this present day of specialization all of us are familiar with the terms in our own field but may find numerous terms in other fields with which we are not familiar. For this reason the dictionary should prove very useful to petroleum geologists as the field of petrology and certain phases of mineralogy are rather removed from our regular reading and the dictionary is particularly good in its definitions of mineral species and igneous rock names. The chemical composition, essential physical characteristics, and, in many instances, the occurrence of each mineral are given. The texture and mineral composition of each igneous rock are outlined. The dictionary is equally complete in other fields of geology.

In the preface the author stated that geophysical terms were also included but unfortunately this part of the dictionary, to have been prepared by another author, was not completed and we note a lack of geophysical terms in the dictionary. Because of this lack of geophysical terms it appears to the reviewer that the author should not have stated, in the preface, that such were included. Common geophysical words such as anomaly, resistivity, refraction, seismograms, and many others are not included.

The dictionary has been reproduced by the planograph method and the printers have done a creditable piece of work. It is regrettable that a reference which will be subject to more use than ordinary books is published with a paper cover but as is the case with most scientific books, the demand for such a dictionary will not be large and evidently every attempt was made to keep the cost of the book as low as possible. Undoubtedly the cost of the dictionary would have been increased excessively had it been bound in cloth and had the type been larger.

We congratulate Miss Rice on the completion of a long, hard and tedious job and the publication of an accurate dictionary. The author has produced a reference book that should prove indispensable to the geologist and has comprehensively defined terms in use in General Geology, Structural Geology, Economic Geology, Physiography, Petrology, Mineralogy, Evolution, Invertebrate and Vertebrate Paleontology and Stratigraphy, giving an occasional definition about which we might quibble, but such definitions are few and readily eclipsed by the sterling quality of the dictionary which is complete from "aa" to "zyklopisch."

RECENT PUBLICATIONS

ARGENTINA AND CHILE

*"El Teraciario carbonifero del sur Argentino y Chileno, su Posición estratigrafica" (The Coal-Bearing Tertiary of Argentina and Chile, Its Stratigraphic Position), by Jose Roman Guiñazu. *Y.P.F. Bol. Inform. Petrol.*, Vol. 17, No. 187 (Buenos Aires, March, 1940), pp. 16–71; 3 sketch maps, 2 pls. of fossil leaves, 2 stratigraphic charts, 45 photographs. In Spanish.

*"Tupungato und Lunlunta, die neuen Ölfelder Westargentiniens" (Tupungato and Lunlunta, the New Oil Fields of Western Argentina), by

Richard Stappenbeck. *Oel und Kohle*, Vol. 36, No. 21 (Berlin, June 1, 1940), pp. 185–90; 8 figs.

CALIFORNIA

*"Possibilities of Eocene Production from the East Side of San Joaquin Valley," by W. T. Woodward. *Petrol. World*, Vol. 37, No. 6 (Los Angeles, June, 1940), pp. 21–22, 60; map and log section.

GENERAL

*"Petroleum Exploration by Means of Soil Analysis," by John W. Merritt. *Oil and Gas Jour.* (Tulsa), Vol. 39, No. 5 (June 13, 1940), pp. 68–69; illus.

**Oil and Petroleum Year Book 1940*, compiled by Walter E. Skinner. 531 pp. Demy 8 vo., bound in red cloth. Gives organization, production, business, financial statistics about 775 companies engaged in producing, transporting, and marketing oil, financing oil development, or otherwise connected with the oil industry. An international reference book. Contains list of trade names, glossary of technical terms, and buyers guide. Published by Walter E. Skinner, 15 Dowgate Hill, Cannon Street, London, E. C. 4. Price: 10*s* net; abroad, 11*s*.

*"Die stratigraphische Bestimmung von Ölsanden mit Hilfe der Schwermineralmethode" (Stratigraphic Determination of Oil Sands by Heavy Mineral Methods), by Joh. Brož. *Oel und Kohle, Petroleum* (Berlin), Vol. 36, No. 19 (May 15, 1940), pp. 173–83; 13 figs.

1940 Petroleum Register. 1,200+ pp. Two large oil directories (The Petroleum Register and World Petroleum Directory) combined in a single edition. Lists 11,000 oil producers in the United States; 500 U. S. refining companies; 500 pipe-line companies; 3,500 oil companies operating in 150 foreign countries; 5,000 professional, technical, and scientific men with their affiliations; *et cetera*. 11.75×8.75×2.5 inches. *Petroleum Register*, Russell Palmer, publisher, 95 River Street, Hoboken, New Jersey. Price: $10 plus transportation; foreign, $12.

**Bibliography and Index of Geology Exclusive of North America*, Vol. 7 (1939), by John M. Nickles, Marie Siegrist, and Eleanor Tatge. Geological Society of America (1940), 419 West 117th Street, New York City. 522 pp. Cloth. 6.75×10 inches, outside dimensions.

*"Direct Discovery of Oil Deposits Is Difficult," by W. V. Howard. *Oil and Gas Jour.* (Tulsa), Vol. 39, No. 6 (June 20, 1940), pp. 27–28; 2 figs.

*"Analysis of Some Factors Involved in Geochemical Prospecting." *Ibid.*, Vol. 39, No. 8 (July 4, 1940), pp. 33–34; 2 figs.

*"Directional Drilling, Surveying, and Polar Core Orientation," by G. L. Kothny. *Ibid.*, pp. 40–45; 20 figs.

**The Development of the Art of Prospecting, with Special Reference to the American Petroleum Industry*, by E. DeGolyer. "An address delivered before Princeton University on December 12, 1939, in the Cyrus Fogg Brackett lectureship in applied engineering and technology." 38 pp. The Guild of Brackett Lectures, Princeton University (1940).

*"Drilling and Production," *Petroleum Engineer* (Dallas, Texas), Vol. 11, No. 10 (July 1, 1940). Annual engineering review issue contains the following articles, in part.

"A Review of Oilfield Development and Drilling Methods," by K. C. Sclater, pp. 13–16.

"Recent Trends in Petroleum Production Research," by Lester C. Uren, pp. 17–34.

"Review of Recent Trends in Production Methods," by H. Lee Flood, pp. 35–49.

"Progress and Trends in Gas-Lift Operations," by S. F. Shaw, pp. 50–62.

"Developments in Production Practice in California," by Wallace A. Sawdon, pp. 63–75.

"Progress and Trends in Water-Flood Districts of Appalachian Areas," by Paul M. Phillippi, pp. 76–107.

"Advancements in Drilling Technique in California," by Wallace A. Sawdon, pp. 108–21.

"Recent Progress in Geophysical, Geochemical, and Electrical Prospecting Methods for Petroleum," by J. Brian Eby, pp. 122–26.

ILLINOIS

*"525 Million Barrels in Sight in Illinois," by Gail F. Moulton. *World Petrol.* (New York), Vol. 11, No. 6 (June, 1940), pp. 30–37; 6 figs. and 2-page oil-field development map.

KANSAS

**Oil and Gas Jour. Kansas Section*, Vol. 39, No. 7 (Tulsa, June 27, 1940), pp. 28–123. Articles on geology, drilling, production, exploration, reserves, natural gas, refining, natural-gasoline manufacture, and pipelines include the following.

"Central Kansas Uplift Has Several Prolific Pays," by E. A. Koester, pp. 50–51; 2 figs.

"Kansas Oil Reserves Estimated at More Than 750,000,000 Barrels," by W. V. Howard, pp. 52, 102.

"Large Gas Reserves Insure Many Years' Supply," by J. H. Page, pp. 69–70, 94–96; 4 figs.

"Stratigraphy of Kansas," by Raymond C. Moore, pp. 73–74, 90–91; 5 figs.

"Most of Kansas' Output Comes from Water-Drive Fields," by Eugene A. Stephenson, pp. 79, 82, 84.

"Mississippi Limestones in Central and Eastern Kansas," by Wallace Lee, pp. 102–12.

PENNSYLVANIA

*"Summit Gas Pool, Fayette County, Pennsylvania," by Chas. R. Fettke. *Pennsylvania Top. and Geol. Survey Prog. Rept. 124* (Harrisburg, June, 1940). 21 pp., topographic and structural map.

TENNESSEE

*"Tennessee's Oil and Gas Prospects," by J. Harmon Overstreet and Hampton G. Maxey. *Oil Weekly*, Vol. 98, No. 5 (Houston, July 8, 1940), pp. 35–41; 3 figs.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 24, NO. 8 (AUGUST, 1940), PP. 1503-1520

THE ASSOCIATION ROUND TABLE

MEMBERSHIP APPLICATIONS APPROVED FOR PUBLICATION

The executive committee has approved for publication the names of the following candidates for membership in the Association. This does not constitute an election but places the names before the membership at large. If any member has information bearing on the qualifications of these nominees, he should send it promptly to the Executive Committee, Box 979, Tulsa, Oklahoma. (Names of sponsors are placed beneath the name of each nominee.)

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Jay Pendleton Wood, Denver, Colo.
Edward W. Ames, Charles W. Henderson, Dart Wantland

ADDITIONAL APPLICATIONS APPROVED FOR PUBLICATION

FOR ACTIVE MEMBERSHIP

Fred J. Agnich, Medan, Sumatra, N.E.I.
Bennett Frank Buie, G. Leslie Whipple, J. P. McCulloch

FOR ASSOCIATE MEMBERSHIP

Helen Elizabeth Dake, Sinton, Tex.
J. L. Tatum, J. Garst, Joseph M. Wilson
Roger Hugh Davis, Hobbs, N. Mex.
Charles R. Rider, Edwin B. Hopkins, J. E. Brantly
Joseph Gleddie, Tilley Station, Alta., Canada
V. E. Monnett, G. E. Anderson, John Galloway
Clinton Charles Kearney, Santander, Colombia, S.A.
W. W. Waring, Richard V. Hughes, Fred M. Bullard
Charles V. Roberts, Jr., Overton, Tex. (Houston Geological Society Student Award Application)

FOR TRANSFER TO ACTIVE MEMBERSHIP

Augustus Bart Brown, Dallas, Tex.
Robert Brown, Alan M. Bateman, R. L. Cassingham
Louis Joseph Simon, Shafter, Calif.
Paul P. Goudkoff, J. M. Hamill, William D. Kleinpell

REPORT OF REPRESENTATIVE TO NATIONAL RESEARCH COUNCIL

CORRECTION

Due to misunderstanding, an error was made in reference to the tectonic map of the United States, mentioned in the first three lines of page 940 of the Association *Bulletin* for May, 1940. This map is now in preliminary form only and is not yet ready for distribution.

On the same page, line 8, read Norman L. Bowen for "Isaiah Bowen."

FREDERIC H. LAHEE

ASSOCIATION COMMITTEES

EXECUTIVE COMMITTEE

L. C. SNIDER, *chairman*, Petroleum Advisers, Inc., New York City
ED. W. OWEN, *secretary*, L. H. Wentz (Oil Division), San Antonio, Texas
HENRY A. LEY, San Antonio, Texas
JOHN M. VETTER, Pan-American Producing Company, Houston, Texas
W. A. VER WIEBE, University of Wichita, Wichita, Kansas

REPRESENTATIVE ON DIVISION OF GEOLOGY AND GEOGRAPHY NATIONAL RESEARCH COUNCIL

A. I. LEVORSEN (1943)

FINANCE COMMITTEE

WALLACE E. PRATT (1941) W. B. HEROY (1942) E. DEGOLYER (1943)

TRUSTEES OF REVOLVING PUBLICATION FUND

GEORGE S. BUCHANAN (1941) E. FLOYD MILLER (1942) FRANK A. MORGAN (1943)

TRUSTEES OF RESEARCH FUND

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R. L. BECKELHYMER (1942)
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J. BOYD BEST (1941)
L. D. CARTWRIGHT (1941)
W. W. CLAWSON (1942)
CAREY CRONEIS (1941)
J. I. DANIELS (1941)
R. K. DEFORD (1941)
C. E. DOBBIN (1941)
H. L. DRIVER (1941)
E. C. EDWARDS (1942)
JAMES F. GIBBS (1942)
DELMAR R. GUINN (1941)
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J. H. MCGUIRT (1941)
C. C. MILLER (1941)
C. L. MOODY (1941)
H. H. NOWLAN (1941)
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PAUL H. PRICE (1941)
ROGER H. SHERMAN (1941)
S. E. SLIPPER (1941)
L. C. SNIDER (1942)
H. B. STENZEL (1941)
L. W. STEPHENSON (1942)
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C. W. TOMLINSON (1941)
W. A. VER WIEBE (1941)
JOHN M. VETTER (1941)
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E. B. WILSON (1941)
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COMMITTEE FOR PUBLICATION

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ALAN J. GALLOWAY	COLEMAN D. HUNTER	H. F. DAVIES
A. B. GROSS	LEWIS W. MACNAUGHTON	MAX L. KRUEGER
ROBERT F. IMBT	CARLETON D. SPEED, JR.	JED B. MAEBIUS
ROBERT C. LAFFERTY, JR.	JAMES L. TATUM	KARL A. MYGDAL
J. T. RICHARDS	FRED H. WILCOX	O. A. SEAGER
J. MARVIN WELLER		H. V. TYGRETT

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A. I. LEVORSEN (1942), *chairman*, 221 Woodward Boulevard, Tulsa, Oklahoma
M. G. CHENEY (1942), *vice-chairman*, Coleman, Texas

1941	1942	1943
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JOHN C. MILLER	ROSS L. HEATON	THOMAS C. HIESTAND
D. PERRY OLCOTT	BELA HUBBARD	JOHN M. HILLS
BEN H. PARKER	PHILIP B. KING	WILLIAM C. KRUMBEIN
WENDELL P. RAND	T. E. WEIRICH	F. B. PLUMMER
F. W. ROLSHAUSEN		W. H. TWENHOFEL
F. M. VAN TUYL		THERON WASSON

GEOLOGIC NAMES AND CORRELATIONS COMMITTEE

JOHN G. BARTRAM (1942), *chairman*, Stanolind Oil and Gas Company, Tulsa, Oklahoma

1941	1942	1943
MONROE G. CHENEY	JOHN E. ADAMS	ANTHONY FOLGER
ROBERT H. DOTT	GENTRY KIDD	BENJAMIN F. HAKE
HAROLD N. HICKEY	HUGH D. MISER	ROBERT M. KLEINPELL
MERLE C. ISRAELSKY	RAYMOND C. MOORE	NORMAN D. NEWELL
C. L. MOODY		CHARLES W. TOMLINSON

SUB-COMMITTEE ON CARBONIFEROUS

M. G. CHENEY (1942), *chairman*, Coleman, Texas

1941	1942	1943
ROBERT H. DOTT	RAYMOND C. MOORE	BENJAMIN F. HAKE
HAROLD N. HICKEY		NORMAN D. NEWELL
		CHARLES W. TOMLINSON

COMMITTEE ON APPLICATIONS OF GEOLOGY

CARROLL E. DOBBIN (1943), *chairman*, U. S. Geological Survey, Denver, Colo.
HENRY C. CORTES (1941), *vice-chairman, geophysics*, Magnolia Petroleum Co., Dallas, Tex.

CAREY CRONEIS (1943), *vice-chairman, paleontology*, University of Chicago, Chicago, Ill.

1941	1942	1943
HAL P. BYBEE	LUTHER E. KENNEDY	H. S. MCQUEEN
E. E. ROSAIRE	CHALMER J. ROY	B. B. WEATHERBY
	EARL A. TRAGER	

SPECIAL COMMITTEES

COMMITTEE ON COLLEGE CURRICULA IN GEOLOGY

FREDERIC H. LAHEE, *chairman*, Sun Oil Company, Dallas, Texas

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WALTER R. BERGER	K. K. LANDES	E. K. SOPER
HAL P. BYBEE	HENRY A. LEY	W. T. THOM, JR.
	JOHN T. LONSDALE	

COMMITTEE TO RECOMMEND A NEW METHOD OF ELECTING OFFICERS

GEORGE S. BUCHANAN, *chairman*, Box 2199, Houston, Texas

N. WOOD BASS	J. V. HOWELL	JOHN N. TROXELL
GLENN C. CLARK	L. C. MORGAN	W. B. WILSON

COMMITTEE ON MIMEOGRAPHED PUBLICATIONS

FRANK R. CLARK, *chairman*, The Ohio Oil Company, Tulsa, Oklahoma

ARTHUR E. BRAINERD	FREDERIC H. LAHEE	E. FLOYD MILLER
GEORGE S. BUCHANAN	A. I. LEVORSEN	FRANK A. MORGAN

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 24, NO. 8 (AUGUST, 1940), PP. 1509-1520

THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS

CONSTITUTION AND BY-LAWS

(Adopted 1918 and amended 1921, 1922, 1923, 1925, 1927, 1928, 1929, 1930, 1932, 1933, 1935, 1936, 1939, and 1940)

CONSTITUTION

ARTICLE I. NAME

This Association shall be called "The American Association of Petroleum Geologists," incorporated under the laws of Colorado the 21st day of April, 1924, for a period of twenty (20) years.

ARTICLE II. OBJECT

The object of this Association is to promote the science of geology, especially as it relates to petroleum and natural gas; to promote the technology of petroleum and natural gas and to encourage improvements in the methods of exploring for and exploiting these substances; to foster the spirit of scientific research amongst its members; to disseminate facts relating to the geology and technology of petroleum and natural gas; to maintain a high standard of professional conduct on the part of its members; and to protect the public from the work of inadequately trained and unscrupulous persons posing as petroleum geologists.

ARTICLE III. MEMBERSHIP

Members

SECTION 1. Any person engaged in the work of petroleum geology or in research pertaining to petroleum geology or technology is eligible to active membership, provided he is a graduate of an institution of collegiate standing, in which institution he has done his major work in geology, or in sciences fundamental to petroleum geology, and in addition has had the equivalent of three years' experience in petroleum geology or in the application of these other sciences to petroleum geology or to research in petroleum geology or technology; and provided further that in the case of an applicant for membership who has not had the required collegiate or university training, but whose standing in the profession is well recognized, he shall be admitted to membership when his application shall have been favorably and unanimously acted upon by the executive committee; and provided further that these requirements shall not be construed to exclude teachers and research workers in recognized institutions, whose work is of such character as in the opinion of the executive committee shall qualify them for membership.

Active members alone shall be known as members.

Life Members

SECTION 2. The executive committee may grant life membership to members who have paid their dues and are otherwise qualified.

Associates

SECTION 3. Any person having completed as much as thirty hours of geology (an hour shall here be interpreted as meaning as much as sixteen recitation or lecture periods of one hour each, or the equivalent in laboratory) in a reputable institution of collegiate or university standing, or who has done field work equivalent to this, is eligible to associate membership, provided at the time of his application for membership he shall be engaged in geological studies in an institution of collegiate or university standing, or shall be engaged in petroleum geology; and any person who is a graduate of an institution of collegiate standing in which he has done his major work in sciences fundamental to petroleum geology or petroleum technology, and who has the equivalent of one year's experience in the application of his science to the study of petroleum geology, shall be eligible to associate membership, provided at the time of his application for membership he shall be engaged in investigations in the broader subject of petroleum geology and technology.

Associate members shall be known as associates.

Associates shall enjoy all the privileges of membership in the Association, save that they shall not hold office, sign applications for membership, or vote; neither shall they have the privilege of advertising their affiliation with the Association in professional cards or professional reports or otherwise.

The executive committee may advance to active membership, without the formality of application for such change, those associates who have, subsequent to election, fulfilled the requirements for active membership.

Election to Membership

SECTION 4. Every candidate for admission as a member or associate shall submit a formal application on an application form authorized by the executive committee, signed by him, and endorsed by not less than three members who are in good standing, stating his training and experience and such other facts as the executive committee shall from time to time prescribe. Provided the executive committee, after due consideration, shall judge that the applicant's qualifications meet the requirements of the constitution, they shall cause to be published in the *Bulletin* the applicant's name and the names of his sponsors. If, after at least thirty days have elapsed since such publication, no reason is presented why the applicant should be not admitted, he shall be deemed eligible to membership or to associate membership, as the case may be, and shall be notified of his election.

SECTION 5. An applicant for membership, on being notified of his election in writing, shall pay full membership dues for the current year and on making such payment shall be entitled to receive the entire *Bulletin* for that year. Unless payment of dues is made within thirty (30) days by those living within the continental United States and within ninety (90) days by those living elsewhere, after notice of election has been mailed, the executive committee may rescind the election of the applicant. Upon payment of dues, each applicant for membership shall be furnished with a membership card for the current year, and until such written notice and card are received, he shall in no way be considered a member of the Association.

Honorary Members

SECTION 6. The executive committee may from time to time elect as hon-

orary members persons who have contributed distinguished service to the cause of petroleum geology. Honorary members shall not be required to pay dues.

ARTICLE IV. OFFICERS AND THEIR DUTIES

Officers

SECTION 1. The officers of the Association shall be a president, a vice-president, a secretary-treasurer, and an editor. These, together with the past president, shall constitute the executive committee and managers of the Association.

SECTION 2. The officers shall be elected annually from the Association at large by written ballot deposited in a locked ballot box by those members, present at the annual meeting, who have paid their current dues and are otherwise qualified under the constitution. Each candidate, when voted for as a candidate for the particular office for which he is nominated, shall be thereby automatically voted for as a candidate for the executive committee for one year, except that candidates for the presidency shall be automatically voted for as candidate for the executive committee for two years.

SECTION 3. No one shall hold the office of president for two consecutive years and no one shall hold any other office for more than two consecutive years except the editor who shall not hold office for more than six consecutive years.

Duties of Officers

SECTION 4. The president shall be the presiding officer at all meetings of the Association, shall take cognizance of the acts of the Association and of its officers, shall appoint such committees as are required for the purposes of the Association, and shall delegate members to represent the Association. He may, at his option, serve on, and may be chairman of, any committee.

SECTION 5. The vice-president shall assume the office of president in case of a vacancy from any cause in that office and shall assume the duties of president in case of the absence or disability of the latter. If the past-president shall for any reason be unable to serve as a member of the executive committee, the president shall fill the vacancy by the appointment of the next available preceding past-president.

A vacancy or disability occurring in the office of vice-president, secretary-treasurer, or editor shall be filled by majority vote of the executive committee, either for the unexpired term or for the period of disability, as the committee may decide. In the case of a tie, the president shall cast the deciding vote.

SECTION 6. The secretary-treasurer shall assume the duties of president in case of the absence of both the president and vice-president. He shall have charge of the financial affairs of the Association and shall annually submit reports as secretary-treasurer covering the fiscal year. He shall receive all funds of the Association, and, under the direction of the executive committee, shall disburse all funds of the Association. He shall cause an audit to be prepared annually by a public accountant at the expense of the Association. He shall give a bond, and shall cause to be bonded all employees to whom authority may be delegated to handle Association funds. The amount of such bonds shall be set by the executive committee and the expense shall be borne by

the Association. The funds of the Association shall be disbursed by check as authorized by the executive committee.

SECTION 7. The editor shall be in charge of editorial business, shall submit an annual report of such business, shall have authority to solicit papers and material for the *Bulletin* and for special publications, and, with the approval of the executive committee, may accept or reject material offered for publication. He may appoint associate, regional, and special editors.

SECTION 8. The officers shall assume the duties of their respective offices immediately after the annual meeting in which they are elected.

ARTICLE V. EXECUTIVE COMMITTEE—MEETINGS AND DUTIES

Executive Committee

SECTION 1. The executive committee shall consist of the president, past-president, vice-president, secretary-treasurer, and editor.

Meetings and Duties

SECTION 2. The executive committee shall meet immediately preceding the annual meeting and at the call of the president may hold meetings when and where thought advisable, to conduct the affairs of the Association. A joint meeting of the outgoing and incoming executive committees shall be held immediately after the close of the annual Association business meeting. Members of the executive committee may vote by proxy on matters which require a unanimous vote.

SECTION 3. The executive committee shall consider all nominations for membership and pass on the qualifications of the applicants; shall have control and management of the affairs and funds of the Association; shall determine the manner of publication and pass on the material presented for publication; and shall designate the place of the annual meeting. They are empowered to establish a business headquarters for the Association, and to employ such persons as are needed to conduct the business of the Association. They are empowered to accept, create, and maintain special funds for publication, research, and other purposes. They are empowered to make investments of both general and special funds of the Association. Trust funds may be created, giving to the trustees appointed for such purpose, such direction as to investments as seems desirable to the executive committee to accomplish any of its objects and purposes, but no such trust funds shall be created unless they are revocable upon ninety (90) days' notice.

ARTICLE VI. MEETINGS

The Association shall hold at least one stated meeting each year, which shall be the annual meeting. This meeting shall be held in March or April at a time and place designated by the executive committee. At this meeting the election of members shall be announced, the proceedings of the preceding meeting shall be read, Association business shall be transacted, scientific papers shall be read and discussed and officers for the ensuing year shall be elected.

ARTICLE VII. AMENDMENTS

Amendments to this constitution may be proposed by a resolution of the executive committee, by a constitutional committee appointed by the presi-

dent, or in writing by any ten members of the Association. All such resolutions or proposals must be submitted at the annual meeting of the business committee of the Association as provided in the by-laws, and only the business committee shall make recommendations concerning proposed constitutional changes at the annual Association business meeting. If such recommendations by the business committee shall be favorably acted on at the annual Association business meeting, the secretary-treasurer shall arrange for a ballot of the membership by mail within thirty (30) days after said annual Association business meeting, and a majority vote of the ballots received within ninety (90) days of their mailing shall be sufficient to amend. The legality of all amendments must be determined by the executive committee prior to balloting.

BY-LAWS

ARTICLE I. DUES

SECTION 1. The fiscal year of the Association shall correspond with the calendar year.

SECTION 2. The annual dues of members of the Association shall be ten dollars ($10.00). The annual dues of associates for not to exceed three years after election shall be six dollars ($6.00); for the second three-year period eight dollars ($8.00); thereafter, the annual dues of such associates shall be ten dollars ($10.00). The annual dues are payable in advance on the first day of each calendar year. A bill shall be mailed to each member and associate before January first of each year, stating the amount of the annual dues and the penalty and conditions for default in payment. Members or associates who shall fail to pay their annual dues by April first shall not receive copies of the April *Bulletin* or succeeding *Bulletins*, nor shall they be privileged to buy Association special publications at prices made to the membership, until such arrears are met.

SECTION 3. On the payment of two hundred dollars ($200.00) any member in good standing shall be declared a life member and thereafter shall not be required to pay annual dues. The funds derived from this source shall be placed in a permanent investment, the income from which shall be devoted to the same purposes as the regular dues.

ARTICLE II. RESIGNATION—SUSPENSION—EXPULSION

SECTION 1. Any member or associate may resign from the Association at any time. Such resignation shall be in writing and shall be accepted by the executive committee, subject to the payment of all outstanding dues and obligations of the resigning member or associate.

SECTION 2. Any member or associate who is more than a year delinquent (in arrears) in payment of dues shall be suspended from the Association. Any delinquent or suspended member or associate, at his own option, may request in writing that he be dropped from the Association and such request shall be granted by the executive committee. Any member or associate more than two years in arrears shall be dropped from the Association. The time of payment of delinquent dues for either one year or two years may be extended by unanimous vote of the executive committee.

SECTION 3. Any member or associate who resigns or is dropped under the

provisions of Sections 1 and 2 of this article ceases to have any rights in the Association and ceases to incur further indebtedness to the Association.

SECTION 4. Any person who has ceased to be a member or associate under Section 1 or Section 2 of this article may be reinstated by unanimous vote of the executive committee subject to the payment of any outstanding dues and obligations which were incurred, prior to the date when he ceased to be a member or associate of the Association.

In the case of any member or associate who has been dropped between the dates of January 1, 1931, and January 1, 1936, for non-payment of dues and who shall apply for reinstatement, the executive committee is authorized, at its discretion, to accept the resignation of such member or associate effective at any date during such period of delinquency, provided, the member shall pay all indebtedness to the Association incurred prior to the date of such resignation including a proper proportion of annual dues as shall be fixed by the executive committee. Such member or associate shall not be entitled to receive the *Bulletin* for any period subsequent to the date when his resignation became effective and prior to his reinstatement.

SECTION 5. Any member or associate who, after being granted a hearing by the executive committee, shall be found guilty of a violation of the code of ethics of this Association or shall be found guilty of a violation of the established principles of professional ethics, or shall be found guilty of having made a false or misleading statement in his application for membership in the Association, may be suspended or expelled from the Association by unanimous vote of the executive committee. The decision of the executive committee in all matters pertaining to the interpretation and execution of the provisions of this section shall be final.

ARTICLE III. PUBLICATIONS

SECTION 1. The proceedings of the annual meeting and the papers presented at such meeting shall be published at the discretion of the executive committee in the Association *Bulletin* or in such other form as the executive committee may decide best meets the needs of the membership of the Association.

SECTION 2. The payment of annual dues for any fiscal year entitles the member or associate to receive without further charge a copy of the *Bulletin* of the Association for that year.

SECTION 3. The executive committee may authorize the printing of special publications to be financed by the Association from its general, publication, or special funds and offered for sale to members and associates in good standing at not less than cost of publication and distribution.

ARTICLE IV. REGIONAL SECTIONS, TECHNICAL DIVISIONS, AND AFFILIATED SOCIETIES

SECTION 1. Regional sections of the Association may be established provided the members of such sections are members of the Association and shall perfect an organization and make application to the executive committee. The executive committee shall submit the application to a vote at a regular annual meeting, an affirmative vote of two-thirds of the members present and voting being necessary for the establishment of such a section; and provided that the Association may revoke the charter of any regional section

by a vote of two-thirds of the members present and voting at a regular annual meeting.

SECTION 2. Technical divisions may be established, provided the members interested shall perfect an organization and make application to the executive committee. The executive committee shall submit the application to a vote at a regular meeting, an affirmative vote of two-thirds of the membership present and voting being necessary for the establishment of such a division. In like manner, the Association may dissolve a division by an affirmative vote of two-thirds of the members present and voting at any annual meeting. A technical division may have its own officers, and it may have its own constitution and by-laws provided that, in the opinion of the executive committee, these do not conflict with the constitution and by-laws of the Association. The executive committee shall be empowered to make arrangements with the officers of the division for the conduct of the business of the division. A division may admit to affiliate membership in the division specially qualified persons who are not eligible to membership in the Association. Technical divisions may affiliate with other scientific societies, with the approval of the executive committee.

SECTION 3. Subject to the affirmative vote of two-thirds of the membership present and voting at an annual meeting, and with legal advice, the executive committee may arrange for the affiliation with the Association of duly organized groups or societies, which by objects, aims, constitution, by-laws, or practice are developing the study of geology or petroleum technology. In like manner and with like advice, the executive committee may arrange conditions for dissolution of such affiliations. Affiliation with the Association need not prevent affiliation with other scientific societies. Members of affiliated societies who are not members of the Association, shall not have the privilege of advertising their affiliation with the Association on professional cards or otherwise.

ARTICLE V. DISTRICT REPRESENTATIVES

The executive committee shall cause to be elected district representatives from districts which it shall define by a local geographic grouping of the membership. Such districts shall be redesignated and redefined by the executive committee as often as seems advisable. Each district shall be entitled to one representative for each seventy-five members, but this shall not deprive any designated district of at least one representative. The representatives so apportioned shall be chosen from the membership of the district by a written ballot arranged by the executive committee. They shall hold office for two years, their term of office expiring at the close of the annual meeting.

ARTICLE VI. COMMITTEES

Appointment and Tenure

SECTION 1. There shall be the following standing committees:

Business Committee
Research Committee
Committee on Geologic Names and Correlations
Committee on Applications of Geology
Committee for Publication

Finance Committee
Trustees of Revolving Publication Fund
Trustees of Research Fund

The president shall appoint all standing committees except the business committee for which provision is hereafter made. Members of all committees except the business committee shall serve for a three-year term, but in rotation, with one-third of the members being appointed each year. The president shall designate the chairmen, annually, shall have power to fill vacancies, and shall notify the members of the committees of their appointment. The president may designate one or more vice-chairmen annually.

In addition to the aforesaid standing committees, the president shall appoint annually or semiannually a resolutions committee, and such special committees as the executive committee may authorize. Special committees shall be appointed for a term of one year. The president shall designate the chairmen of such committees.

Business Committee

SECTION 2. The business committee shall act as a council and advisory board to the executive committee and the Association. This committee shall consist of the executive committee, not more than five members at large appointed annually by the president, two members elected by and from each technical division, and the district representatives. The president shall also appoint annually a chairman and a vice-chairman, but neither of these need be one of those otherwise constituting the business committee. The secretary-treasurer shall act as secretary of the business committee. If a district or technical representative is unable to be present at any meeting of the committee he may designate an alternate, who, in the case of a district representative, may or may not be a resident of the district he is asked to represent, and the alternate, on presentation of such a designation in writing, shall have the same powers and privileges as a regularly chosen representative. The business committee shall meet the day before the annual meeting at which all proposed changes in the constitution or by-laws shall be considered, all old and new business shall be discussed, and recommendations shall be voted for presentation at the annual meeting.

Research Committee

SECTION 3. The purpose of the research committee is the advancement of research, particularly within the field of petroleum geology. The committee shall consist of twenty-four members unless a different number is authorized by the executive committee.

Committee on Geologic Names and Correlations

SECTION 4. The purpose of the committee on geologic names and correlations is to lend assistance to authors on problems of stratigraphy and nomenclature and to advise the editor and executive committee in regard to the propriety of the use of stratigraphic names and correlations in papers submitted for publication by the Association. The committee shall consist of fifteen members unless a different number is authorized by the executive committee.

Committee on Applications of Geology

SECTION 5. The object of the committee on applications of geology is to advise and promote ways and means for informing the general public on all phases of geology, particularly on the natural occurrence of oil and gas underground, the methods of searching for these substances, and the methods of exploiting them. The committee shall consist of twelve members unless a different number is authorized by the executive committee.

Committee for Publication

SECTION 6. The purpose of the committee for publication is to assist in securing desirable manuscripts for publication in the *Bulletin* or other publications of the Association. The committee may also assist in securing papers for delivery at the annual meetings. The committee shall consist of twenty-four members unless a different number is authorized by the executive committee.

Finance Committee

SECTION 7. The finance committee shall act as financial advisers to the executive committee. The committee shall consist of three members. If a member of the finance committee should be elected to the executive committee he shall resign from the finance committee and the president shall appoint a member of the Association to complete his unexpired term.

Trustees of Revolving Publication Fund

SECTION 8. Before any publication project shall be undertaken with the use of the revolving publication fund the approval of the trustees and the executive committee must be secured. There shall be three trustees. If a trustee should be elected to the executive committee he shall resign as a trustee and the president shall appoint a member of the Association to complete his unexpired term.

Trustees of Research Fund

SECTION 9. Before any research work may be undertaken with the use of money from the research fund, the approval of the trustees and the executive committee shall be secured. There shall be three trustees. If a trustee shall be elected to the executive committee he shall resign as a trustee and the president shall appoint a member of the Association to complete his unexpired term.

Resolutions Committee

SECTION 10. The resolutions committee shall be charged with the duty of presenting at the annual and semi-annual meetings resolutions expressing the Association's appreciation and thanks to those who have worked and contributed to the success of the meetings.

ARTICLE VII. AMENDMENTS

These by-laws may be amended by vote of three-fourths of the members present and voting at any annual meeting, provided that such changes shall have been recommended to the meeting by the business committee and provided that their legality shall be determined by the executive committee prior to publication.

CODE OF ETHICS OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS

OBJECT. The object of this Association is to promote the science of geology, especially as it relates to petroleum and natural gas; to promote the technology of petroleum and natural gas and to encourage improvements in the methods of exploring for and exploiting these substances; to foster the spirit of scientific research amongst its members; to disseminate facts relating to the geology and technology of petroleum and natural gas; to maintain a high standard of professional conduct on the part of its members; and to protect the public from the work of inadequately trained and unscrupulous men posing as petroleum geologists. (Constitution, Article II.)

ARTICLE I. GENERAL PRINCIPLES

SECTION 1. The practice of petroleum geology is a profession. It is the duty of those engaged in it to be guided by the highest standards of professional conduct and to subordinate reward and financial gain thereto.

SEC. 2. The confidence of the public and of the oil industry can be won and held only by the practice of the highest ethical principles.

SEC. 3. Honesty, integrity, fairness, candor, fidelity to trust, inviolability of confidence, and conduct becoming a gentleman are incumbent upon every member of the Association.

ARTICLE II. RELATION OF GEOLOGIST TO PUBLIC AND PROFESSION

SECTION 1. A geologist should avoid and discourage sensational, exaggerated, and unwarranted statements, especially those that might induce participation in unsound enterprises.

SEC. 2. A geologist should not knowingly permit the publication of his reports or maps for the purpose of raising funds without legitimate and sound development in view.

SEC. 3. A geologist may accept for his services in the making of a report an interest in the property reported on, but it is desirable that the report state the fact of the existence of the interest.

SEC. 4. A geologist should not give an opinion or make a report without being as fully informed as might reasonably be expected, considering the purpose for which the information is desired. The opinion or report should make clear the conditions under which it is made.

SEC. 5. A geologist may publish simple and dignified business, professional, or announcement cards, but should not solicit business by other advertisements, or through agents, or by furnishing or inspiring exaggerated newspaper or magazine comment. The most worthy advertisement is a well merited reputation for professional ability and fidelity. This can not be forced, but must be the outcome of character and conduct.

ARTICLE III. RELATION OF GEOLOGIST TO EMPLOYER

SECTION 1. A geologist should protect, to the fullest extent possible, the interests of his employer so far as consistent with the public welfare and his professional obligations.

SEC. 2. A geologist who finds that his obligations to his employer conflict with his professional obligations should notify his employer of that fact. If the objectionable condition persists, the geologist should sever his connection with his employer.

SEC. 3. A geologist should not allow himself to become or remain identified with any enterprise of questionable character.

SEC. 4. A geologist should make known to his prospective employer any oil or gas interest which he holds in the region of his prospective employment.

SEC. 5. A geologist, while employed, should not directly or indirectly acquire any present or prospective oil or gas interest without the express consent of his employer.

SEC. 6. A geologist retained by one client, should, before accepting engagement by another, notify them of this affiliation, if in his opinion the interests might conflict.

SEC. 7. A geologist who has made an investigation for a client should not, without the client's consent, seek to profit from the economic information thus gained, or report on the same subject for another client, until the original client has had full opportunity to act on the report.

SEC. 8. A geologist should not accept direct or indirect compensation from both buyer and seller, without consent of both parties; or from parties dealing with his employer without the employer's consent.

SEC. 9. A geologist should observe scrupulously the rules, customs, and traditions of his employer as to the use or giving out of information or the acquisition of interests, both while employed and thereafter; and, except as permitted by such rules, customs, and traditions or by the consent of the employer, he should not seek to profit directly or indirectly from the economic information gained while so employed.

SEC. 10. A geologist employed by a State geological survey should not permit private professional work or the holding of private mineral interests in the state to interfere with his duty to the public or to lessen the confidence of the public in the survey. The preferable course is to avoid such private work and interests.

SEC. 11. A geologist should not divulge information given him in confidence.

ARTICLE IV. RELATION OF GEOLOGIST TO OTHER GEOLOGISTS

SECTION 1. A geologist should not falsely or maliciously attempt to injure the reputation or business of a fellow geologist.

SEC. 2. A geologist should not knowingly compete with a fellow geologist for employment by reducing his customary charge.

SEC. 3. A geologist should give credit for work done to those, including his assistants, to whom credit is due.

ARTICLE V. DUTY TO THIS ASSOCIATION

SECTION 1. Every member of the Association should aid in preventing the election to membership of those who lack moral character or the required education and experience.

SEC. 2. A member of this Association who has definite evidence of the violation of the established principles of professional ethics by another should report the facts to the executive committee.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 24, NO. 8 (AUGUST, 1940), PP. 1521-1523

Memorial

DONALD C. BARTON[1]

On July 8, 1939, only a few days after completion of his term as a member of this Division's Advisory Committee on Post-Doctorate Fellowships, Donald Clinton Barton died at Houston, Texas. He had previously served a three-year term, from July 1, 1934, as a representative on this Division, from the Geological Society of America. He was a member of the technical staff of the Humble Oil and Refining Company, acting in an advisory capacity in geological and geophysical work in both of which he had had abundant experience.

Barton was of good old New England stock; modest, composed, kindly, of highest principles; simple in his living; a careful thinker, and an indefatigable worker. His studies and associations carried him into many lines of investigation. He wrote over 150 contributions in the fields of physiography, stratigraphy, structural geology, and geophysics. He was a leader in deduction from observed facts and in directing research toward both scientific and practical ends. For several years, he was active as Chairman of the Research Committee of The American Association of Petroleum Geologists.

Barton was a member of many technical associations, not only in this country, but also abroad. He was founder and an early president of the Society of Petroleum Geophysicists. From March, 1938, to March, 1939, he was president of The American Association of Petroleum Geologists. In his death his colleagues have lost an inspiring guide and counsellor, and science has lost one of its most ardent contributors.

F. H. LAHEE

GEORGE ALFRED KROENLEIN
(1898–1940)

George Kroenlein, 41, died January 16, 1940, at Barnes Hospital, St. Louis, of nephrosis, a rare and progressive kidney break-down of many months duration. He went to St. Louis from Midland, Texas, to undertake a recently devised treatment—an experimenter to the end. He is survived by his widow Mayme, of Midland, and his daughters, Virginia Castle, 4, and Sylvia May, 2 years younger. In St. Louis he leaves his parents, Henry and Ida Richter Kroenlein, and four younger sisters: Irma, Katharine, Ida, and Adele.

He was born at St. Louis, August 31, 1898, and there graduated from Soldan High School, June, 1916. Next was a B.Sc. degree in metallurgical engineering at the Missouri School of Mines and Metallurgy, at Rolla, in June, 1920. An indulgent father urged him to further formal education

[1] Excerpt from minutes of the annual meeting of the Division of Geology and Geography, National Research Council, held on April 27, 1940. Presented by F. H. Lahee, and adopted by the Division by a rising vote. A memorial of Dr. Barton, prepared by Wallace E. Pratt, was published in this *Bulletin*, Vol. 23, No. 12 (December, 1939), pp. 1888–96.

which was completed in 1921 with a B.Sc. degree in mining engineering, also from Rolla. Here he became a member of Tau Beta Pi, honorary engineering society, and of Phi Kappa Phi. In athletics his activities were confined to football, and he always retained an interest in this sport. The summer holidays were vacations in change only to such an active person, and it was then, when roads were trials, that he pioneered in the use of the trailer while touring the Mountain states. His disposition toward travel, his incessant objective reading and study, and an inclination for cultivating the friendships of men with ideas were apparently developed during these formative years while at school.

His active life, for 19 years, was crowded, varied, and so replete with the personal satisfaction of work well done that to the very end he was formulating plans for the future. His early experience was with oil companies, then as his confidence developed he in turn became consulting oil geologist, potash expert, broker, and finally in his resourcefulness organized his own geophysical company. At various times during the years 1920 to 1923 he worked for the Sinclair Oil and Gas Company in Kansas, Oklahoma, and Mexico. In 1924–25 he was in charge of geological and petroleum engineering for Gilliland Oil Company, whose operations extended to a number of states, including New Mexico. The Edwards Plateau and surrounding territory absorbed his energies between 1926 and 1931, with his consulting headquarters first at Del Rio and then at San Angelo, Texas. In addition to surface work and some drilling, he explored the Pecos River by boat, and was able ultimately to capitalize on his exhaustive knowledge of this large province.

Already he was looking to the potash deposits of the northern parts of the Delaware basin. In 1932 he moved to Carlsbad, New Mexico, and for 2 years studied, with a characteristic thoroughness, the outcrops on the fringes of the basin, and German literature on saline deposits. He examined in detail cuttings of the salt section of wells drilled to the lower dolomites for oil, and the cores of tests made in exploration for potash. The high points and less confidential phases of this investigation are fortunately recorded in his paper entitled, "Salt, Potash, and Anhydrite in Castile Formation of Southeast New Mexico," Volume 23, Number 11 (November, 1939), *Bulletin* of The American Association of Petroleum Geologists. While at Carlsbad he married Mayme Ida Castle of that city, September 20, 1934. In 1935 he was secretary of New Mexico Geological Society, and in 1936 was elected president of the organization. During these years he conducted a field trip in the Guadalupe Mountains for the first combined meeting of this society and the West Texas Geological Society, and a second joint meeting later which examined the two principal potash mines in United States. Subsequently he addressed the West Texas Geological Society, at Midland, on the subject of the Delaware basin, and in March, 1939, at Oklahoma City, discussed potash deposits at the annual meeting of The American Association of Petroleum Geologists.

In 1934, coincidentally with the softening of the potash market, he reentered oil activites in southeastern New Mexico, and in 1937 moved to Lovington, New Mexico. Here, in 1938, he organized the Midland Exploration Company after satisfying himself of the utility of the electrical-resistivity method in exploring for structure. In the Fall of 1938 contracts in the newly opened fields of Illinois took him to that state, where he con-

tinued his electrical exploration until physically incapacitated in July of 1939.

His recreations were few and simple; frequent fishing trips with friends, picnics in the open with his family, with an occasional hunting excursion, were satisfying to him. His mind was so objective in its eagerness to assimilate and use information relating to his work that he had little time for the more conventional diversions. Mr. Kroenlein was a student by nature, and although his interests were diversified throughout the years he always concentrated exhaustively on the particular problem in hand at the particular time. Critical instincts were such that traditional theories and practises did not deter him in evolving original ideas and their application. These were just as readily discarded when he found it desirable to adopt the new. His grasp of a wealth of minute detail of geology and the application to the larger concepts often, during a discussion, astonished the listener. Likewise, he had at the same time the peculiar faculty for both the practical and the theoretical. He early saw the advantages of The American Association of Petroleum Geologists and became a member in 1922. His years of professional life were filled with many interests and activities during which he easily made friends in the Mid-Continent and especially in the Southwest, friends who have benefited from association with him and who, with affection, will long remember George and his considerate, friendly, and enthusiastic ways.

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AT HOME AND ABROAD

CURRENT NEWS AND PERSONAL ITEMS OF THE PROFESSION

WILLIAM J. MILLARD, whose address is the Army and Navy Club, Manila, Philippine Islands, went on an expedition into the interior of southern Yunnan, in June. For several years he has been doing mining geological work in the Philippines, Indo-China, and China.

L. O. WIRINGA, geologist with the Caribbean Petroleum Company in Maracaibo, Venezuela, for the past 2 years, may now be addressed in care of Well Surveys, Incorporated, 412 S. Kenosha Avenue, Tulsa, Oklahoma.

MALVIN G. HOFFMAN, consulting geologist and recently chief geologist of the Midco Oil Corporation, is now with the Geochemical Service Corporation, Tulsa, Oklahoma.

JOSEPH M. WILSON, vice-president and director of the Salt Dome Oil Corporation, Houston, has moved to Dallas, Texas, where he is engaged in private geological practice. He will maintain his connections with the Salt Dome Oil Corporation in a consulting capacity.

CHESTER M. CREBBS, president of the Mene Grande Oil Company, Caracas, Venezuela, is visiting in the United States.

VERNER JONES, of the Magnolia Petroleum Company, Mattoon, Illinois, recently spoke on "Rotary Drilling Problems of the Illinois Basin," before Illinois Basin chapter of the American Petroleum Institute Division of Production.

JOHN F. MASON, recently in the producing department of the Socony-Vacuum Oil Company, New York, is now in the department of geology, Princeton University, Princeton, New Jersey.

H. F. SMILEY, recently with the Hamilton Petroleum Company, has opened an office as consulting petroleum geologist at 624 Hamilton Building, Wichita Falls, Texas.

RUTHVEN W. PIKE may be addressed in care of the Standard Oil Company of Argentina, Ave. Rogue Saenz Pena 567, Buenos Aires, Argentina.

W. R. FARLEY has left the Lion Oil Refining Company, El Dorado, Arkansas, and is in the exploration department of the Union Sulphur Company, Sulphur, Louisiana.

C. R. NICHOLS has resigned as district geologist of the Sun Oil Company, and is engaged in consulting work. His office will continue to be in McAllen, Texas.

L. C. SMITH, geologist with the Sun Oil Company, has been transferred from Dallas to McAllen, Texas.

JEROME A. CHEVALIER, consulting geologist of Tulsa and Muskogee, Oklahoma, died at Muskogee, July 15, at the age of 62.

FRANK G. EVANS, geologist with the Shell Oil Company, Inc., recently read a paper on "Reconnaissance Photogeologic Study of a Part of the Texas Gulf Coast," before the South Texas Geological Society at Corpus Christi.

A General Conference on Applied Nuclear Physics, sponsored by the American Institute of Physics in coöperation with the Massachusetts Institute of Technology, will be held during the week of October 28–November 2, 1940, at the Massachusetts Institute of Technology, Cambridge, Massachusetts. Papers in the geology sessions include: "Techniques and Standards in Terrestrial Radioactivity Measurements," "Geochemical Applications of Radioactivity," "Radioactive Methods of Geologic Age Determinations," "Geophysical Applications of Nuclear Physics." Those wishing to attend should register by letter as soon as possible and not later than October 1. Letters and inquiries should be addressed to Professor Robley D. Evans, general chairman, Conference on Applied Nuclear Physics, Massachusetts Institute of Technology.

ARTHUR WADE, recently on the Oil Advisory Committee of the Australian Government at Canberra, is now with the Shell Company, Shell House, Ann Street, Brisbane, Queensland, Australia.

BRUCE WHITCOMB has moved from Groesbeck, Texas, to accept a position with the Well Surveys, Inc., 412 South Kenosha Avenue, Tulsa, Oklahoma.

W. W. WARING has resigned from the Tropical Oil Company in Colombia and is with the International Petroleum Company, Casilla 803, Guayaquil, Ecuador.

HARRIS COX has changed his address from Babo, New Guinea, to 1311 Republic Bank Building, Dallas, Tex.

ALBERT GREGERSEN, president of the Pacific Section of the Association, announces the 17th annual fall meeting of the Section will be held at the Ambassador Hotel, Los Angeles, California, on November 7 and 8, 1940. President Gregersen may be addressed in care of The Texas Company, Los Angeles.

H. A. SPROWLS has resigned as vice-president of the Kentucky Natural Gas Corporation, and will engage in producing activities in Illinois and Indiana with offices at Vincennes, Indiana.

H. W. WYNN, geologist with the Sinclair Prairie Oil Company, recently stationed at Shawnee, Oklahoma, is now at Youngstown, Ohio.

TOM M. GIRDLER, geologist with the Sinclair Prairie Oil Company, has moved from Shawnee, Oklahoma, to Wichita Falls, Texas.

B. DYKSTRA, formerly of Hollywood, California, is assistant manager, Compania de Petroleo Shell de Colombia, Bogota, Colombia.

WILLIAM A. NEWTON has accepted a geological trainee position with the Carter Oil Company, Tulsa, Oklahoma.

W. H. THRALLS, consulting geologist, 819½ Main Street, San Antonio, Texas, has returned from Trinidad after spending a year there for the Antilles Petroleum Company.

O. A. SEAGER, of the Carter Oil Company, has changed his address from Billings, Montana, to Bismarck, North Dakota.

ROY LEBKICHER has returned from London. He may be addressed at 225 Bush Street, San Francisco, California.

M. N. BRAMLETTE has changed his address from the United States Geological Survey, Washington, D. C., to the department of geology at the University of California, West Los Angeles, California.

W. K. ESGEN, of the Trinity Petroleum Company, has moved from Corpus Christi to Houston, Texas.

TOMÁS SUERO is employed by the Pure Oil Company at Olney, Illinois.

A. H. RICHARDS, consulting geologist, Petroleum Building, Oklahoma City, Oklahoma, has returned from a year's work with the Argentine Government Oil Fields at Mendoza, Argentina.

DORSEY HAGER is chief geologist of the recently organized Tex-Harvey Oil Company, Great National Life Building, Dallas, Texas.

K. C. SPOONER, division geologist for the Atlantic Refining Company at Houston, Texas, has been transferred to a similar position at Jackson, Mississippi.

H. H. TRAGER, geologist with the Atlantic Refining Company, has been transferred from Shreveport, Louisiana, to Houston, Texas.

R. E. MCPHAIL, geologist with the Phillips Petroleum Company, recently at Wichita Falls, Texas, is now at Corpus Christi, Texas.

C. A. BAIRD, who was with the Danish American Prospecting Company at Copenhagen last spring, has resumed his work with the Mene Grande Oil Company at Caracas, Venezuela.

W. E. HEATER, who was with the Ned. Pacific Petroleum Mij., at The Hague, has returned to 225 Bush Street, San Francisco, California.

W. A. J. M. VAN DER GRACHT, formerly supervisor of mines for the Netherlands, may be addressed at Huize Jachduin, 36 Eeuwige Laan, Bergen, N. H., Netherlands.

KARL A. MYGDAL, with the Pure Oil Company, has been transferred from Wichita Falls to Fort Worth, Texas.

W. C. KRUMBEIN, of the University of Chicago, addressed meetings of the Pacific Section of the Association, on his Geological Society of America research subject, "Fundamental Properties of Sediments in Relation to Environments of Deposition," at Los Angeles, June 19, and at Bakersfield, July 24.

ROBERT J. DAVIS, of the Shell Oil Company, Inc., has moved from Saint Louis to 50 West 50th Street, New York City.

FIELD TRIPS

WEST TEXAS GEOLOGICAL SOCIETY, SEPTEMBER 28-29

A two-day field trip in the vicinity of Carlsbad, New Mexico, will be led by Ronald K. DeFord, George D. Riggs, and Neil H. Wills. It will deal mainly with the younger Permian rocks, and will attempt to show the relation of the surface outcrops to well known subsurface formations of southeastern New Mexico and West Texas. It is subtitled, "A Round Trip from Subsurface to Surface and Return."

The party will assemble in Carlsbad, Friday night, September 27, at the La Caverna Hotel. All reservations should be made through Georges Vorbe, Midland, Texas. As a large attendance is expected, you should communicate with him immediately to insure receiving good accommodations. Further details will be published in the September *Bulletin*.

APPALACHIAN GEOLOGICAL SOCIETY, OCTOBER

The executive committee of the Appalachian Geological Society has planned a field trip to be held some time in October for the purpose of studying the possibilities of deeper production in the Appalachian area from exposures in the Niagara Gorge and some distance east. Geologists from other parts of the country are invited. The trip is planned for two days with a dinner meeting and at least half a day in the Oriskany fields near the New York-Pennsylvania State line. Geologists interested in this trip are requested to send their names immediately to the president of the Appalachian Geological Society, J. R. Lockett, Ohio Fuel Gas Company, Box 117, Columbus, Ohio, who will place the names on a mailing list for the itinerary and other details. An indication of the number of persons interested is necessary to make arrangements.

KANSAS GEOLOGICAL SOCIETY, AUGUST 26–SEPTEMBER 1

The Fourth Annual Field Conference of the Kansas Geological Society will be held in the Black Hills of South Dakota, the Hartville uplift, Laramie Mountains, and Medicine Bow Range of Wyoming, August 26 to September 1. S. H. Knight, head of the department of geology, University of Wyoming, and State geologist, is director. He will be ably assisted by men familiar with the details of the stratigraphy and structure of this most interesting area.

Increased interest in the subsurface stratigraphy of the Great Plains, principally Nebraska and South Dakota, and in the Pennsylvanian production in the Lance Creek field of eastern Wyoming assures a large attendance. Special emphasis will be placed on the Cambro-Ordovician and Permo-Pennsylvanian rocks. Correlations with the Mid-Continent and central

Wyoming regions will be advanced. Further information may be secured from the office of the Kansas Geological Society, 412 Union National Bank Building, Wichita, Kansas.

The general itinerary follows.

Aug. 25, Sun. P.M.	Convene at Rapid City, South Dakota.
26, Mon. A.M.	Rapid City. Proceed to northern Black Hills. Whitewood-Deadwood problem. Permo-Pennsylvanian beds. Homestake mine. Night at Rapid City.
27, Tues. A.M.	Rapid City. Central and southern Black Hills. Night at Hot Springs.
28, Wed. A.M.	Hot Springs. Central and southern Black Hills. Night at Lusk, Wyoming.
29, Thurs. A.M.	Lusk, Wyoming. Permo-Pennsylvanian of Hartville uplift. Night at Lusk.
30, Fri. A.M.	Lusk. Hartville uplift. Night at Douglas.
31, Sat. A.M.	Douglas. Sections south of Douglas. Big Muddy oil field and Jacksons Canyon in P.M. Night at Casper.
Sept. 1, Sun. A.M.	Casper. Alcova Dam. Seminoe Plateau. Hanna Basin. Walcott. Saratoga. Medicine Bow Mountains. Possibly might stop at summer camp of University of Wyoming.
2, Mon.	Symposium on Permian problems.

Private automobiles will be used for transportation. For persons without cars, the committee will undertake to provide seats in the cars of other participants.

The registration fee is $12.50 and includes the price of one copy of the guide book. Additional copies of the guide book may be purchased for $7.50. All participants must pay the registration fee, no matter how much of the conference they attend. Further information may be secured from the office of the Kansas Geological Society, 412 Union National Bank Building, Wichita, Kansas.

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Dinner meetings, first and third Mondays of each month, 6:15 P.M., Auditorium Hotel.

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The Texas Company, Mattoon
Secretary-Treasurer - - - James G. Mitchell
The Pure Oil Company, Clay City

Meetings will be announced.

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KANSAS GEOLOGICAL SOCIETY
WICHITA, KANSAS

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Vice-President - - - - - Harold O. Smedley
Skelly Oil Company
Secretary-Treasurer - - - - - Lee H. Cornell
Stanolind Oil and Gas Company
Manager of Well Log Bureau - Harvel E. White

Regular Meetings: 7:30 P.M., Allis Hotel, first Tuesday of each month. Visitors cordially welcomed.

The Society sponsors the Kansas Well Log Bureau which is located at 412 Union National Bank Building.

LOUISIANA

THE SHREVEPORT GEOLOGICAL SOCIETY
SHREVEPORT, LOUISIANA

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Vice-President - - - - - - - - J. D. Aimer
Arkansas Fuel Oil Company
Secretary-Treasurer - - - Weldon E. Cartwright
Tide Water Associated Oil Company
Historian - Anna Minkofsky, Shell Oil Co., Inc.

Meets the first Friday of every month, 7:30 P.M., Civil Courts Room, Caddo Parish Court House. Special dinner meetings by announcement.

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MICHIGAN GEOLOGICAL SOCIETY

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Vice-President - - - - - - - W. F. Brown
Mt. Pleasant
Secretary-Treasurer - - - - - C. H. Riggs
Michigan Geological Survey
21 Sheldon, N.E., Grand Rapids
Business Manager - - - - - S. G. Bergquist
Michigan State College, East Lansing

Meetings: Monthly dinner meetings rotating between Saginaw, Mt. Pleasant, and Lansing. Informal dress.

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LAKE CHARLES, LOUISIANA

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Atlantic Refining Company
Vice-President - - - - - - - - - Coe Mills
Ohio Oil Company, Lafayette, Louisiana
Secretary - - - - - - - - - E. M. Baysinger
Box 210
Treasurer - - - - - - - - - Baker Hoskins
Shell Oil Company, Inc., Box 598

Meetings: Luncheon 1st Wednesday at Noon (12:00) and business meeting third Tuesday of each month at 7.00 P.M. at the Majestic Hotel. Visiting geologists are welcome.

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MISSISSIPPI GEOLOGICAL SOCIETY
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Southern Natural Gas Company, Box 2563
Vice-President - - - - - - Urban B. Hughes
Consulting Geologist
Secretary-Treasurer - - - - - Tom McGlothlin
Gulf Refining Company, Box 1105

Meetings: First and third Wednesdays of each month, from October to May, inclusive, at 7:30 P.M., Edwards Hotel, Jackson, Mississippi. Visiting geologists welcome to all meetings.

OKLAHOMA

OKLAHOMA CITY GEOLOGICAL SOCIETY
OKLAHOMA CITY, OKLAHOMA

President - - - - - - Albert S. Clinkscales
Consulting Geologist, Colcord Building
Vice-President - - - - - - Clyde H. Dorr
Hall-Briscoe, Inc., 2118 First National Bldg.
Secretary-Treasurer - - - - - F. Mabry Hoover
Empire Oil & Refg. Company, Box 4577

Meetings, Ninth Floor, Commerce Exchange Building: Technical Program, second Monday, each month, 8:00 P.M.; Luncheons, every Monday, 12:15 P.M.

THE STRATIGRAPHIC SOCIETY OF TULSA
TULSA, OKLAHOMA

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Amerada Petroleum Corporation, Box 2040
Vice-President - - - - - - Wendell S. Johns
The Texas Company
Secretary-Treasurer - - - - - Floyd L. Swabb
Sun Oil Company, Box 1348

Meetings: Second and fourth Wednesdays, each month, from October to May, inclusive, at 8:00 P.M.

OKLAHOMA

ARDMORE GEOLOGICAL SOCIETY
ARDMORE, OKLAHOMA

President - - - - - - - W. Morris Guthrey
The Texas Company, Box 539
Vice-President - - - - - - Paul L. Bartram
Phillips Petroleum Company
Secretary-Treasurer - - - - - Tom L. Coleman
U. S. Geological Survey, Box 719

Meetings: First Tuesday of each month, from October to May, inclusive, at 7:30 P.M., Dornick Hills Country Club.

SHAWNEE GEOLOGICAL SOCIETY
SHAWNEE, OKLAHOMA

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Amerada Petroleum Corporation, Box 896
Vice-President - - - - - - - M. C. Roberts
The Texas Company
Secretary-Treasurer - - - - F. Spencer Withers
Atlantic Refining Company

Meets the fourth Monday of each month at 8:00 P.M., at the Aldridge Hotel. Visiting geologists welcome.

TULSA GEOLOGICAL SOCIETY
TULSA, OKLAHOMA

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The Pure Oil Company, Box 271
1st Vice-President - - - - - John G. Bartram
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2nd Vice-President - - - - - Ronald J. Cullen
Sun Oil Company
Secretary-Treasurer - - - - - L. M. Wilshire
Skelly Oil Company, Box 1650
Editor - - - - - - - - - John L. Ferguson
Amerada Petroleum Corporation
Associate Editor - - - - - Hiram J. Tandy
Route 7

Meetings: First and third Mondays, each month, from October to May, inclusive, at 8:00 P.M., University of Tulsa, Kendall Hall Auditorium. Luncheons: Every Thursday (October-May), Michaelis Cafeteria, 507 South Boulder Avenue.

TEXAS

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DALLAS, TEXAS

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DeGolyer, MacNaughton, and McGhee
Secretary-Treasurer - - - D. M. Collingwood
Sun Oil Company, Box 2880
Executive Committee - - - Paul W. McFarland

Meetings: Regular luncheons, first Monday of each month, 12:15 noon, Petroleum Club. Special night meetings by announcement.

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TYLER, TEXAS

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Pure Oil Company
Vice-President - - - - - - Frank R. Denton
Stanolind Oil and Gas Company
Secretary-Treasurer - - - - - C. I. Alexander
Magnolia Petroleum Company, Box 780

Meetings: Monthly and by call.
Luncheons: Every Monday at 12:00 noon, Blackstone Hotel.

TEXAS

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FORT WORTH, TEXAS

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Vice-President - - - - - Louis H. Freedman
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The Pure Oil Company, Box 2107

Meetings: Luncheon at noon, Worth Hotel, every Monday. Special meetings called by executive committee. Visiting geologists are welcome to all meetings.

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HOUSTON, TEXAS

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Humble Oil and Refining Company, Box 2180

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Sun Oil Company, Box 2659

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Luncheons and evening programs will be announced.

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Secretary-Treasurer - - - - Robert N. Kolm
1742 Milam Building, San Antonio

Executive Committee - - - - - - L. W. Storm

Meetings: Third Friday of each month alternately in San Antonio and Corpus Christi. Luncheon every Monday noon at Milam Cafeteria, San Antonio, and at Plaza Hotel, Corpus Christi.

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Univ. Texas, Dept. of Geology

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Univ. Texas, Dept. of Geology

Meetings: Every third Friday at 8:00 P.M. at the University of Texas, Geology Building 14.

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MIDLAND, TEXAS

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Vice-President - - - - - - - - Dana M. Secor
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Secretary-Treasurer - - - - - Fred F. Kotyza
Tide Water Associated Oil Company, Box 181

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Editor - - - - - - - - - Robert C. Lafferty
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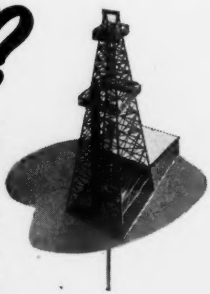

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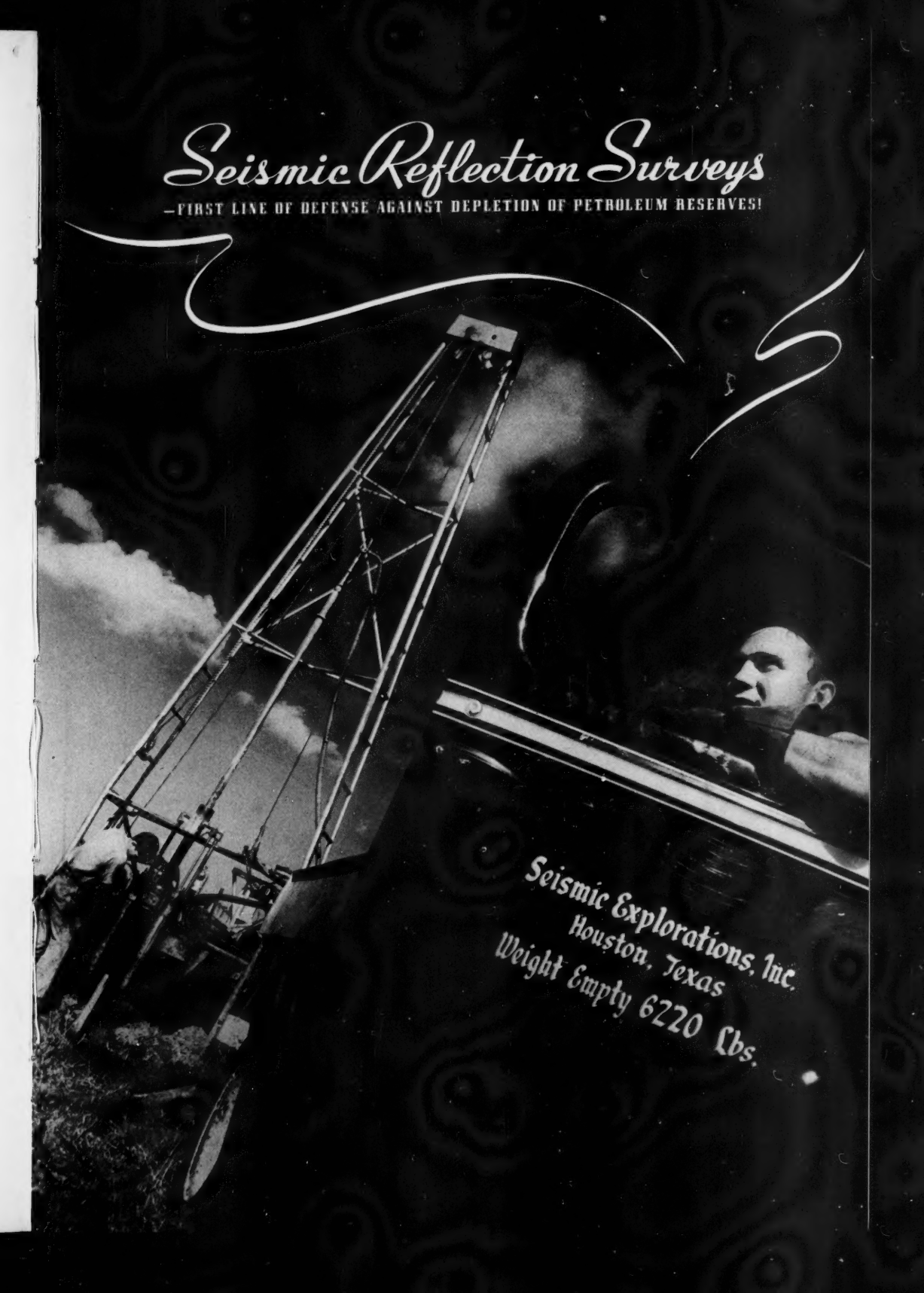
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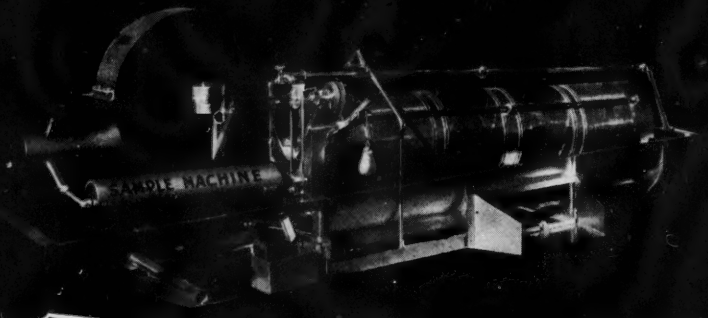

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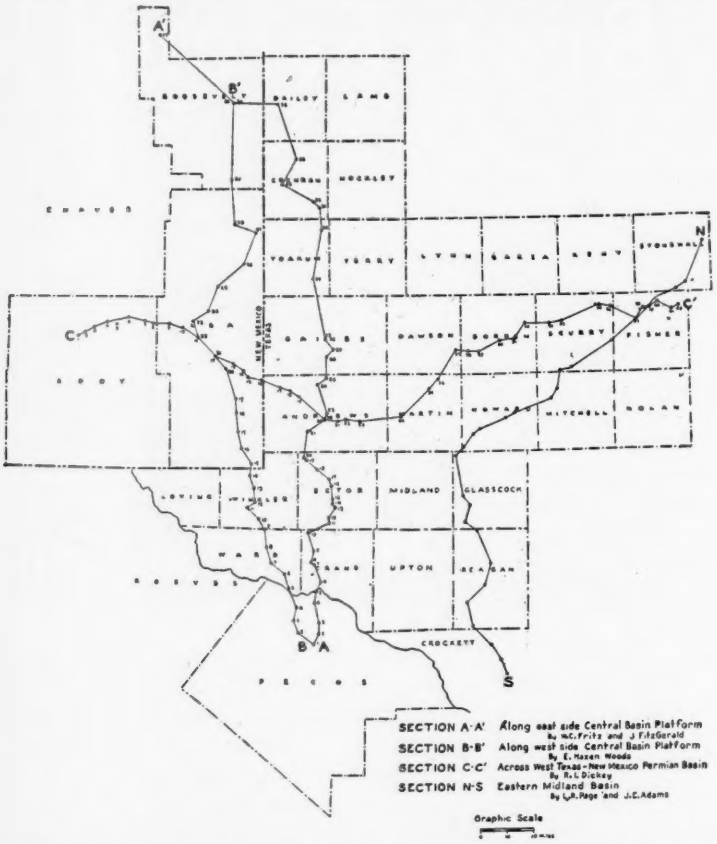

Announcement of these West Texas-New Mexico stereograms and cross sections, made in the January, 1940, Bulletin, is here repeated for those who desire to take advantage of this offer. These sections, shown only in skeleton or reduced form in the West Texas-New Mexico symposium, are available as blue-line paper prints, *with complete, original stratigraphic details not shown in the Bulletin.*

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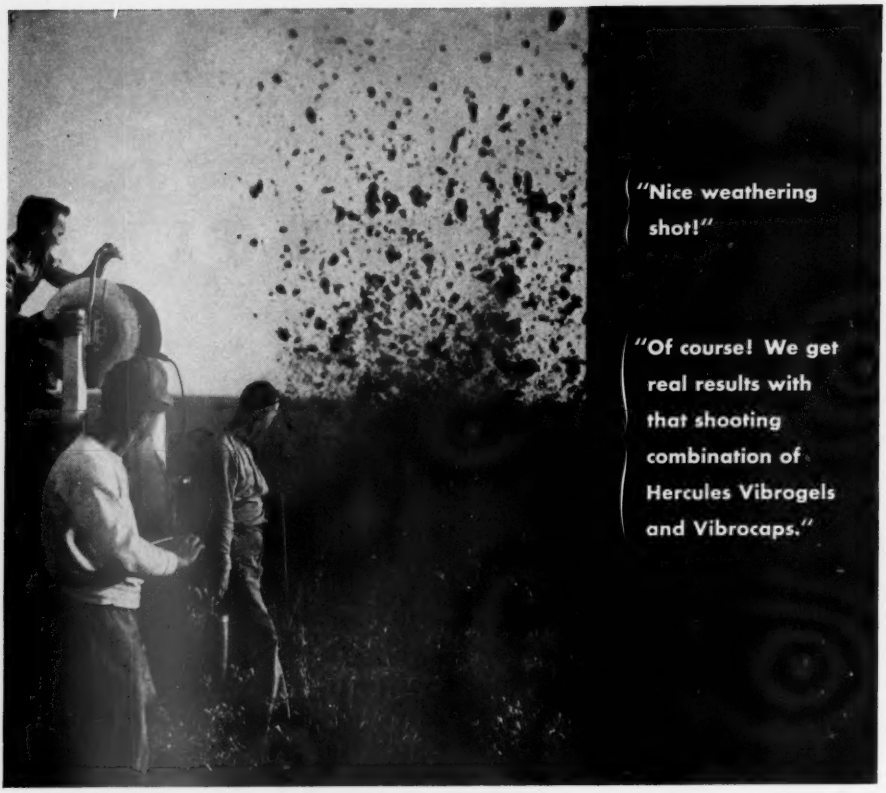
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2,112,845	Venezuela	1815
2,170,435	Brazil	24,749
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2,183,964	Australia	105,418
2,192,525	Canada	367,692
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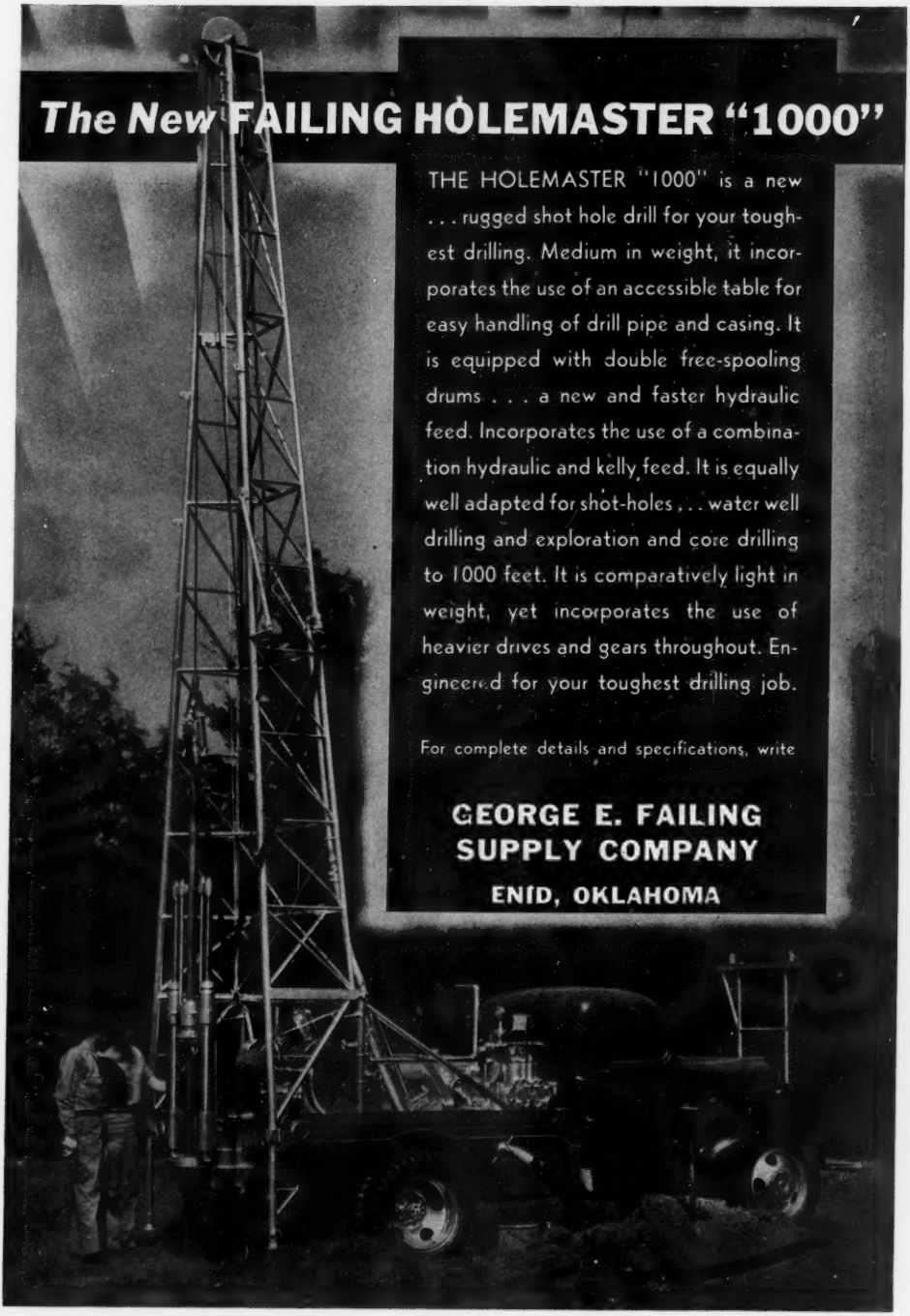
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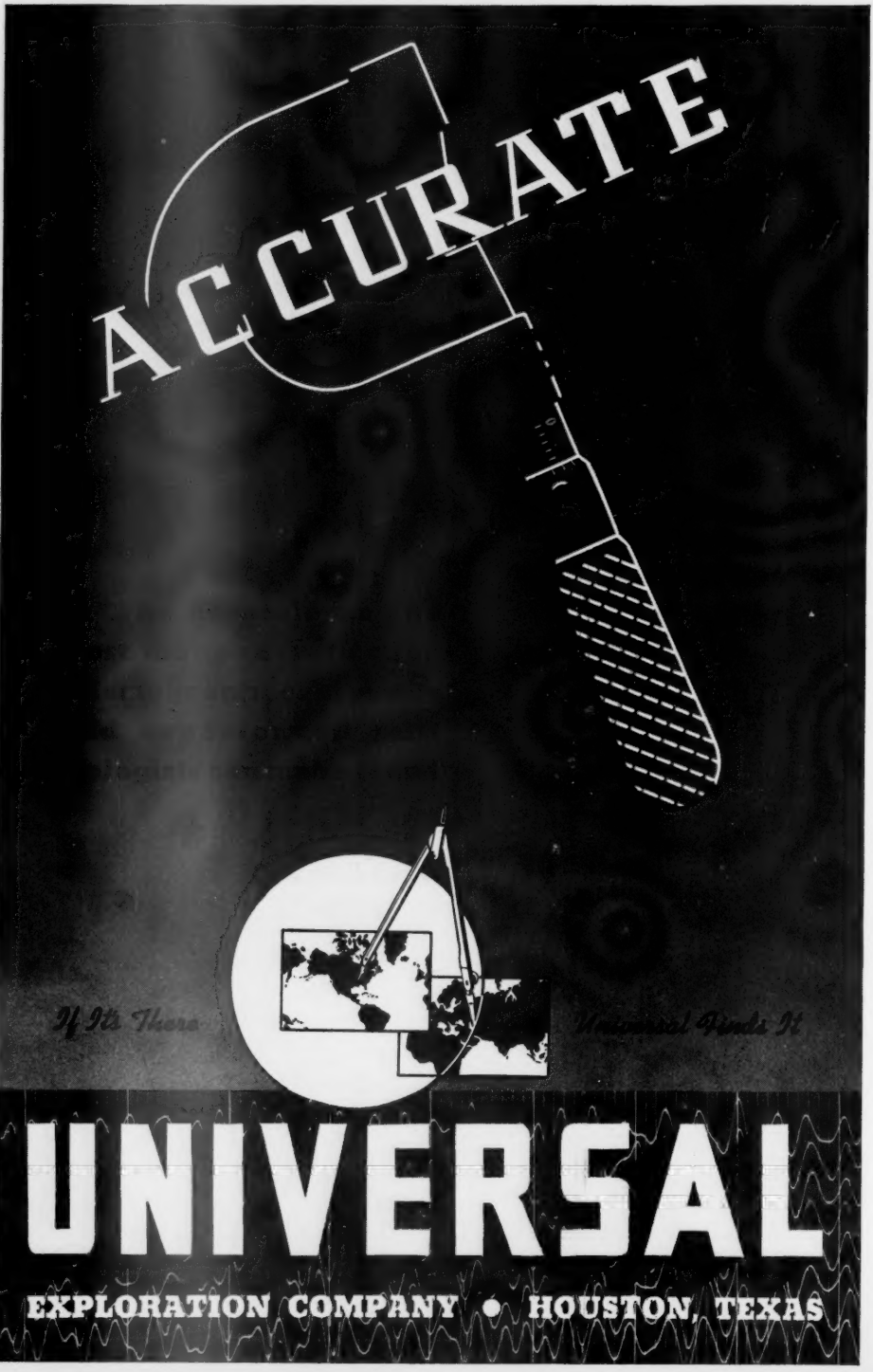
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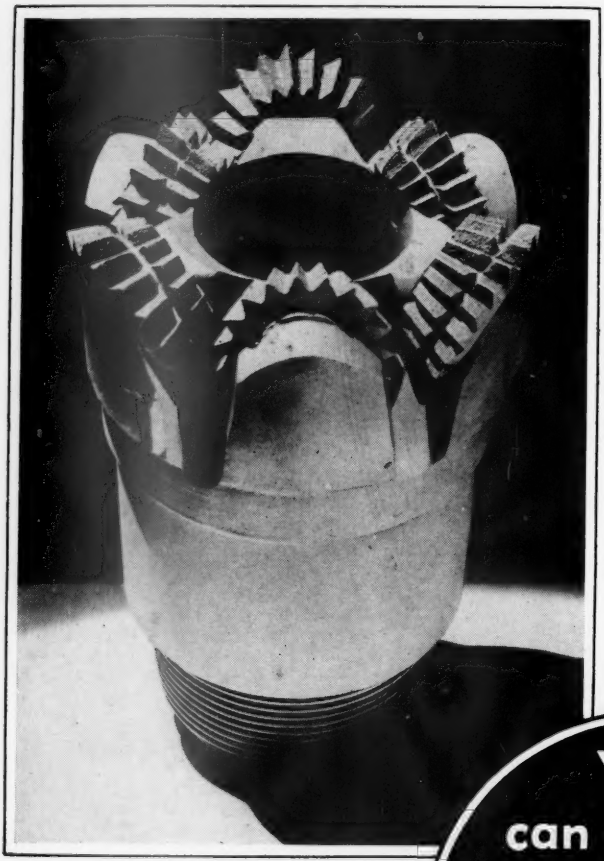

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